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THE PLANET MARS

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by

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TRANSLATOR'S FOREWORD

Some years have now elapsed since the publication, in English, of any serious work dealing with our fascinating neighbour, the Red Planet Mars.

It seems, therefore, a great pity that the recent authoritative account by M. Gérard de Vaucouleurs, astronomer at the Observatoire du Houga and Secretary for the Commission for the study of Mars of the Société Astronomique de France (the equivalent of the B.A.A. Mars Section) should be available only to those persons who have a knowledge of French; and I have—somewhat diffidently—produced a translation that will, I hope, be found of use to Martian workers in general.

This English edition has been thoroughly revised and brought up to date by the author, who has also given great assistance in the preparation of the translation, and to whom I should like to express my particular gratitude. I should also like to express my gratitude to Mr. P. M. Ryves, Director of the B.A.A. Mars Section, for most valuable help.

As Mr. Ryves said when reviewing the French original in the 'Journal' of the British Astronomical Association, 'No student of Mars can afford to be without this up-to-date little book.'

PATRICK A. MOORE

Glencathara,
Worsted Lane, East Grinstead,
Sussex. 1st September 1949.

FOREWORD

There is no planet which has been the object of so much research and study as Mars; nor has any other planet given rise to so many controversies, heated discussions and —it must also be said—so many more or less serious books.

Astronomers have devoted their lives to him; observatories have been dedicated to him like temples. Aerography ('Αρησ, Mars) has had many trusty and faithful followers . . . unfortunately, though our language has been enriched in this way it has not always been possible to say the same concerning our real knowledge of the planet.

Everybody has heard of the 'canals' of Mars; these strange appearances are described by some people as proof of the industrious activity of 'Martians', yet others will not admit that they are anything but persistent optical illusions. This question of the Martian canals has given rise to interminable debates for more than half a century, and—despite the affirmations of some badly-informed people—these arguments are still going on; we cannot consider them closed when numbers of qualified specialists firmly hold on to their original ideas.

And, since many people have represented this as the crucial point of the Martian question and the eventual aim of all research, this great quarrel about the canals has brought much discredit upon the study of the planet.

Such discredit is not justified, or, it would be better to say, is no longer justified; and this little book will achieve

its object if it makes any contribution towards the rehabilitation of such research, for, as was said by the eminent Director of the Paris Observatory, André Danjon, speaking of Mars:

'It is not by nature that an object of study is or is not scientific, but only by the manner of looking at it.'

We must admit that observers have too often begun the study of Mars at the wrong end, and have striven to scrutinize detail at the extreme limit of visibility although so many fundamental problems still await solution, and such a number of major phenomena remain unexplained.

Happily, the situation is tending to improve, for in the course of the last twenty-five years new or improved methods of investigation, making use of the progress of theoretical and experimental physics, have enabled us to obtain reliable quantitative results, and to clear up certain important aspects of the Martian problem.

Doubtless these results do not suffice to banish all difficulties from the problem, nor to reconcile all the divergencies of view; but in other cases people have too often maintained that the contradictions between the results of different methods of investigation are irreconcilable—when a methodical examination of the facts would have revealed definite possibilities of agreement.

Without pretending, naturally, to give a definitive and complete picture of Mars, this little book will at least give the reader an objective view of the present state of the Martian problem, as it aims at enabling him to appreciate the results obtained without seeking to delude him as to the state of our knowledge; it will supply him impartially with all the theories advanced to account for the problems that have not yet been definitely solved.

GENERALITIES

The Two Years' Opposition Period, and the Greater Cycle of Fifteen Years

In the family of planets, Mars comes immediately after us in order of distance from the Sun; the distance from the Earth to the Sun is 93 million miles, that from Mars to the Sun is on the average 142 million miles. Consequently the planet can recede from us $142+93=235$ million miles when it is on the far side of the Sun, that is to say in conjunction, or can approach to within $142-93=49$ million miles when it is behind us with reference to the Sun, that is to say in opposition.

Now the Earth, as everybody knows, makes one circuit around the Sun in a year, or almost exactly 365 days; Mars, which is farther away, moves less quickly—obeying the laws of Kepler (15 miles a second, against the 18¾ of the Earth)—and describes a larger orbit; it takes Mars almost two years to complete one revolution, more exactly 687 days.

It is therefore many months, in fact almost the complete two years, between successive passages favourable for observation.

These passages are far from being equally favourable, because the distance between Mars and the Earth is not the same at each opposition. We know that the orbits of the planets are not circular, but elliptic; and the eccentricity of the orbit of Mars alters the planet's distance from the Sun from 129 million miles at perihelion (minimum) to 154 million miles at aphelion. As a result the

closeness of approach to the Earth depends upon the year, according to the parts of the orbits of the Earth and Mars near which opposition occurs; and the perigee distance (smallest distance from the Earth) may vary from 62 million miles at aphelic oppositions to 37 million miles at perihelic ones. In the first case the planet subtends an angle of about 14″, in the second a maximum of 25″ (25″ is the apparent diameter of a 4-inch ball seen at a distance of half a mile). The opposition period being rather greater than the Martian year (779 days on the average, against 687), we can see that successive oppositions are displaced along the orbit of Mars, travelling completely round in 15 (terrestrial) years, the synchronizing interval of the two periods concerned. Most favourable oppositions therefore occur at intervals of a little more than 15 years; the last were those of 1877 and 1879, 1892 and 1894, 1909, 1924, and then 1939 and 1941; the next will take place in 1956. Between these come oppositions of least approach; the most unfavourable oppositions of recent years were those of 1901, 1916, 1933 and 1948.

Difficulty of Researches

THE DISTANCE OF THE PLANET. The preceding circumstances only complicate studies that are already quite difficult enough. We can see why this is so when we reflect that even at the most favourable opposition the planet, at a distance of 35 million miles, is still 150 times farther away than the Moon, and that the generally used magnifying power is in the region of 300, never much exceeding 600; in other words, we can never, even in the greatest instruments, see Mars as well as we can see the

Moon with good binoculars; and in most cases the observer of Mars is not so well placed as he would be if he set out to study the Moon with the naked eye.

UNCERTAINTY OF VISUAL OBSERVATIONS. It is no exaggeration to say that if, in summer, we look at the Moon when it is just rising above the level of a tarred road that has been warmed by the Sun all day, we shall get a good picture of the conditions under which observers of Mars generally find themselves. We can well imagine, after that, the difficulty of researches into the condition of the planet; and we can better understand what uncertainty must prevail as to conclusions drawn from visual observations only. What should we know about the Moon if we had never been able to observe it except under these conditions, even if we were allowed a few glimpses with low-power binoculars? Evidently almost nothing. However, despite the errors, and the often very problematical character of their conclusions, we must admire the patient observers who have not hesitated to attack the problem even under such a handicap; without allowing themselves to be discouraged, and with no resources but sheer visual observation, they have accumulated, in the course of the last three cycles, an immense number of drawings—which make up, after all, a far from negligible contribution to our total knowledge.

As to the physical methods used in the course of the last cycle, they themselves are not without their difficulties, which will be dealt with later. Their results are not always conclusive up to now; but they are new, and the future belongs to them.

The Globe, the Day, the Seasons, the Satellites

Let us now examine some of the well-known and most important geometrical and dynamical elements of the globe.

THE GLOBE. Its diameter is about 4,200 miles, that is to say, just more than half that of the Earth and double that of the Moon. As the mass of Mars is about a tenth of the Earth's, the gravitational pull on its surface is only 0·38 of what it is here; consequently a man weighing 14 stone on the Earth would feel very light on Mars, as he would weigh only just over 5 stone—a sensation that would not, perhaps, be without its inconvenience.

The Martian globe is very slightly flattened at the poles; its flattening (about $\frac{1}{190}$) is so near the theoretical limit ($\frac{1}{178}$) assigned by celestial mechanics to a homogeneous body that we can accept a rather exceptional internal constitution, the density being nearly constant from the surface to the centre—around the mean value of 3·9 (for instance, 2 to 3 near the surface, 4 to 5 at the centre), circumstances very different from those prevailing on the Earth (density 2 to 3 at the surface, against 8 to 10 at the centre).

THE DAY. The rotation period of Mars, that is to say the length of the Martian day, is known with high precision; it is 24h 37m 22·6s, very nearly equal to that of the Earth, which is, as everybody knows, 24h, or more exactly 23h 56m 4·1s (sidereal day); we should not, therefore, feel strange on Mars with regard to the duration of day and night.

THE SEASONS. Nor is the march of the seasons on Mars essentially different from that on the Earth. We know, of

course, that the phenomenon of the seasons arises from the inclination of the axis of rotation to the plane of the orbit. Now this angle is $23\frac{1}{2}°$ for the Earth, and approximately $24°$ or $25°$ for Mars. On the other hand, the seasons are much longer than on the Earth, for the Martian year is almost double ours; and the seasons are also more unequal, since the eccentricity of Mars' orbit is more marked; thus

the Southern spring or Northern autumn lasts 146 days,
the Southern summer or Northern winter lasts 160 days,
the Southern autumn or Northern spring lasts 199 days,
the Southern winter or Northern summer lasts 182 days.

Astronomers usually mark the epochs of the Martian year by the corresponding position on the orbit, or Heliocentric Longitude.

THE SATELLITES. We have yet to mention the two satellites, veritable miniature worlds scarcely more than ten miles in diameter, circling rapidly round the planet—the first, Phobos, in 7h 39m, the second, Deimos, in 30h 18m. They must provide but insignificant moonlight during the Martian nights. The closer, Phobos, revolves round the planet in less than a Martian day, and would present to an observer on Mars the unique peculiarity of rising in the west and setting in the east, passing through the complete cycle of its phases in four hours.

Old Observations and Maps

Let us recall, very briefly, the old ideas about the

planet, and the progress in mapping it by visual observations only.

We can count at least in hundreds of thousands the number of observations accumulated during the three centuries that have elapsed since the invention of the telescope. Little by little, with the progress of astronomical optics, the principal characteristics of Martian topography have been made clear, thanks to the studies of a succession of astronomers like Cassini, Huygens and Hooke in the seventeenth century; Maraldi, Schröter and Herschel in the eighteenth, and Beer and Mädler, Secchi, Kayser, Lockyer and Dawes in the nineteenth.

Thus we already knew, three-quarters of a century ago, that Mars presented on its surface bright permanent patches—rosy or orange in colour—supposed to be continents, and dark patches, bluish or greenish in colour, which were regarded as seas; other glittering white variable spots, covering the polar regions and apparently similar to the icy areas and ice-fields of the Earth; and sometimes transitory whitish spots, obliterating the permanent features, recognized as clouds—proving the existence of an atmosphere around the planet.

Nevertheless, these old observations now interest us mainly from an historical point of view; since then far more powerful instruments have been turned on Mars, and greater numbers of astronomers have seriously devoted themselves to the study of the planet. Great divergencies of view remain, but nearly all the precise and detailed observations that help to make up E. M. Antoniadi's general map were accumulated between 1877 and 1924.

As the patches on Mars are, in the main, permanent,

they have been given names, taken principally from geography or Greco-Latin mythology; all observers of Mars know thus the Syrtis Major, one of the patches visible in the smallest instruments; the Sinus Meridiani, the celebrated forked bay of the meridian which serves as the standard for Martian longitudes, just as Greenwich does for the Earth; the Margaritifer Sinus, the Gulf of Pearls; the Solis Lacus, the Lake of the Sun; Mare Sirenum, the Sea of the Sirens, etc. (See Plate I and Key Map.)

Since 1924, the actual charting of Mars has scarcely been improved; on the other hand, progress has been made in a much more important direction—to which reference will be made later.

All this patient study enables us to give now a precise and comprehensive idea of the phenomena observable on the surface of the planet.

THE POLAR CAPS

The features that we first notice on Mars are the white patches that cover the polar regions; these are the most obvious of all the Martian markings, and are patently variable.

Seasonal Variations

Let us begin to observe Mars at the end of winter—for example, that of the southern hemisphere in 1939 or 1941 —and we see that the polar cap is very extensive, going down as far as lat. 60°. It covers at this time a spherical cap subtending about 60° from the centre, that is 10 million square kilometres (4 million square miles).

In the course of the following months it progressively diminishes in extent, at first slowly, then more and more quickly. Near the middle of spring rifts appear in it, breaking up the main cap and showing up regions of varied brightness. The minor spots, isolated from the main cap, persist for a time and then disappear finally during the Martian summer of the hemisphere concerned. The polar cap itself continues to decrease, and becomes so minute that it seems to be on the point of vanishing completely; but generally it does not do so. Near the end of the summer, when the cap has become very small, some bright diffuse spots are seen to appear in the polar regions, of a duller whiteness than that of the cap; they extend rapidly and finish by completely covering the polar zone and even a good part of the temperate

zone as far as lat. 40° or 50°. These bright moving veils persist thus throughout the autumn and winter, and do not break up and disappear until the end of the winter. We then see the reappearance of the polar cap; it is rather dull at first, but then becomes white once more, brilliant and very extended as in the preceding year at the corresponding epoch (Pl. II, 1–8).

Then the seasonal cycle of these phenomena recommences, and the process is repeated each year with great regularity — such regularity, in fact, that we can draw up permanent tables, giving the dimensions of the polar cap for any epoch of the Martian year.

Irregularity of the Seasonal Cycle. However, this regularity is not perfect and rigorous; in certain years the polar cap diminishes a little more quickly than usual, in others a little less quickly; or, more exactly, the

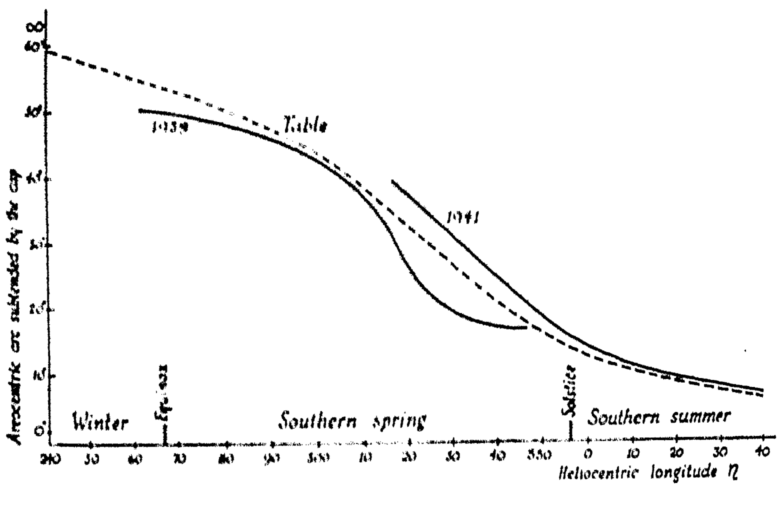


Fig. 1. Shrinkage of the Martian South Polar Cap in 1939 and 1941 according to the observations of the author, as compared with the permanent table of E. M. Antoniadi.

diminution occurs a little ahead of or behind that predicted. For example, in 1939, the south polar cap was ahead of Antoniadi's permanent table by a matter of 15 days, whereas in 1941 it was ten days late. Alternatively, we can say that in certain years the polar cap is a little smaller than normal, as in 1939, or a little larger, as in 1941. (See figure 1)

TOPOGRAPHICAL PECULIARITIES. It has long been established that certain circumstances of the diminution are bound up with the topography and climate of the polar regions of Mars; for instance, the dark rifts cutting up the cap, the regions of greatest brightness, the fragments left isolated from the main mass in the course of the spring, always occur at the same points on the surface, thus disclosing differences of constitution or level. Likewise, we always observe that the last remnant of the south polar cap is not centred on the pole, but some distance away—about 250 miles—at lat. 7°, long. 30°. Similarly, the pole of coldness on Earth does not coincide with the pole of rotation.

These phenomena are especially obvious in the case of the south polar cap, for this cap is always tilted towards us during the most favourable oppositions (as in 1939 and 1941). But doubtless the phenomena in the north polar regions are very similar, with a time-lag of half a Martian year. As would be expected, we note that the northern cap, formed during a shorter autumn and winter than that of the southern hemisphere (306 days instead of 381) —due to the inequality of the Martian seasons—is less extensive than the southern cap; it covers on an average only 50° at the end of the winter, whereas the other attains 60°.

The Dark Fringe

All the phenomena so far reviewed suggest, unmistakably, that we have under our eyes extensive snow-fields which, formed during winter in the polar night and under the cloak of the layers of cloud and mist, melt progressively at the return of the Sun during the summer; and that has certainly been the general opinion of observers for a long time.

But if we are really dealing with ordinary snow, that melts under the Sun, there ought to be water issuing from the melting—always supposing that the atmospheric pressure is sufficient.

Now we actually do see, round the edge of the polar cap, a dark band which accompanies it as it shrinks; and this suggests the existence, if not of a polar sea, at least of a zone several hundred miles in width where the soil is softened and dampened by the melting ice. We know, of course, that moistened or damp ground is much darker than ground which is dry.

But on this subject there are strong differences of opinion; some observers have emphasized that the dark band does not seem to obey the laws of perspective, which require that the band—if it is real—should appear broader to the right and left of the cap than on the central meridian; also that it is scarcely visible on photographs, suggesting—if the photographs are at all comparable in clarity with visual observation—that the fringe is illusory, and arises simply from a subjective effect of contrast due to its close proximity to the sparkling polar whiteness.

However, other observers have noticed that this dark

fringe often has a patchy appearance along the bright uniform regions, and that in general it is darker near the less brilliant parts of the cap; that if we observe it through a red screen the polar cap loses—owing to its colour—nearly all its brilliance, yet the dark fringe does not disappear; and that spots as brilliant as the polar caps have sometimes been seen on other regions of the planet's disk (in general they may be regarded as clouds), which do not appear to be ringed by dark bands.

Here indeed is a set of observations that cannot be satisfactorily explained by the theory of contrast, and appears to demonstrate, in a very convincing fashion, the reality of the dark fringe.

We should at least bear these observations in mind, because, as so often happens, each of the two theories may contain part of a more complex truth.

RECENT RESULTS. The observations that I secured in 1939 at Le Houga Observatory show that, in general, the brighter the cap and its adjacent area, the darker appears the fringe, betraying the effect of subjective contrast; but after correcting for this effect the fringe remains clearly darker than the neighbouring regions, so that it is a real phenomenon, and not a sheer illusion.

It has also been noticed that the dark fringe is not generally visible towards the end of the winter when the polar cap is very extended, nor during the summer when it is at a minimum; and that the fringe presents its full development only during the spring, an additional proof of its reality.

This last observation becomes very significant when we compare it numerically with the decrease of the polar cap.

In fact, we can deduce from these observations—first,

the shape or profile of the polar cap; secondly, the relative quantities of snow disappearing during the winter until such and such a date; and thirdly, the relative mass of snow that vanishes each day, i.e. the speed of transformation. Now it is very remarkable to notice, at least after my results of 1939, that this speed shows a sharp 'peak' coinciding with the period of visibility of the real dark fringe, as though this fringe could not begin to manifest itself until the speed of transformation had become sufficiently great.

We can only suppose, therefore, that at this point the amount of moisture caused by the melting of the ice becomes too great to be wholly absorbed by the atmosphere.

The Process of Disappearance of the Polar Caps

This leads us to ask what causes the transformation of the vanished snow. What indeed? But 'melting', naturally, you will say. Now, this is exactly what has been keenly disputed; actually a solid body which receives heat can melt, that is to say, pass into the liquid state, but can also, in the cases of certain bodies under particular conditions, pass directly from the solid to the gaseous condition—that is to say, sublime.

Now the feebler the atmospheric pressure, the more favourable the conditions for vaporization, and in consequence of the low pressures that prevail on Mars, it seems quite likely that sublimation assumes a preponderant rôle, essential in any explanation of the seasonal disappearance of the Martian polar caps.

Yet, ought we to go so far as to regard this as the sole phenomenon producing the observed effects in these regions, or should we—as others maintain, having re-

gard to the dark fringe and its details—retain the ordinary phenomenon of melting, of the conversion into liquid water?

It is most probable that these two phenomena are coexistent, but in what proportion it is extremely difficult to fix as yet.

If we must come to a provisional conclusion, it must however be admitted, in consideration of our definite knowledge as to the atmospheric pressure and temperature of the Martian polar regions, that sublimation ought to be the fundamental phenomenon causing the disappearance of the polar caps on the surface; but the reality of the dark fringe indicates a periodical melting taking place as well at the periphery of this cap, during a part of the spring. The water produced can only remain in the liquid state in cases where certain favourable circumstances are combined—and they are normally combined in the polar regions every year at the same epochs. Indeed, the concordance of the development of the dark fringe with the maximum speed of transformation makes one think that water can only exist when the atmosphere above is rendered sufficiently damp by the general evaporation of the cap, which does not happen except between after the start of the main transformation and some time before the cap is at its smallest.

This idea seems to fit in well with the general picture of what is observed upon the planet; it takes account of the progress of physical knowledge, and, at the same time, of recent results.

Thickness and Structure of the Polar Caps

In any case, we must agree that—contrary to old ideas

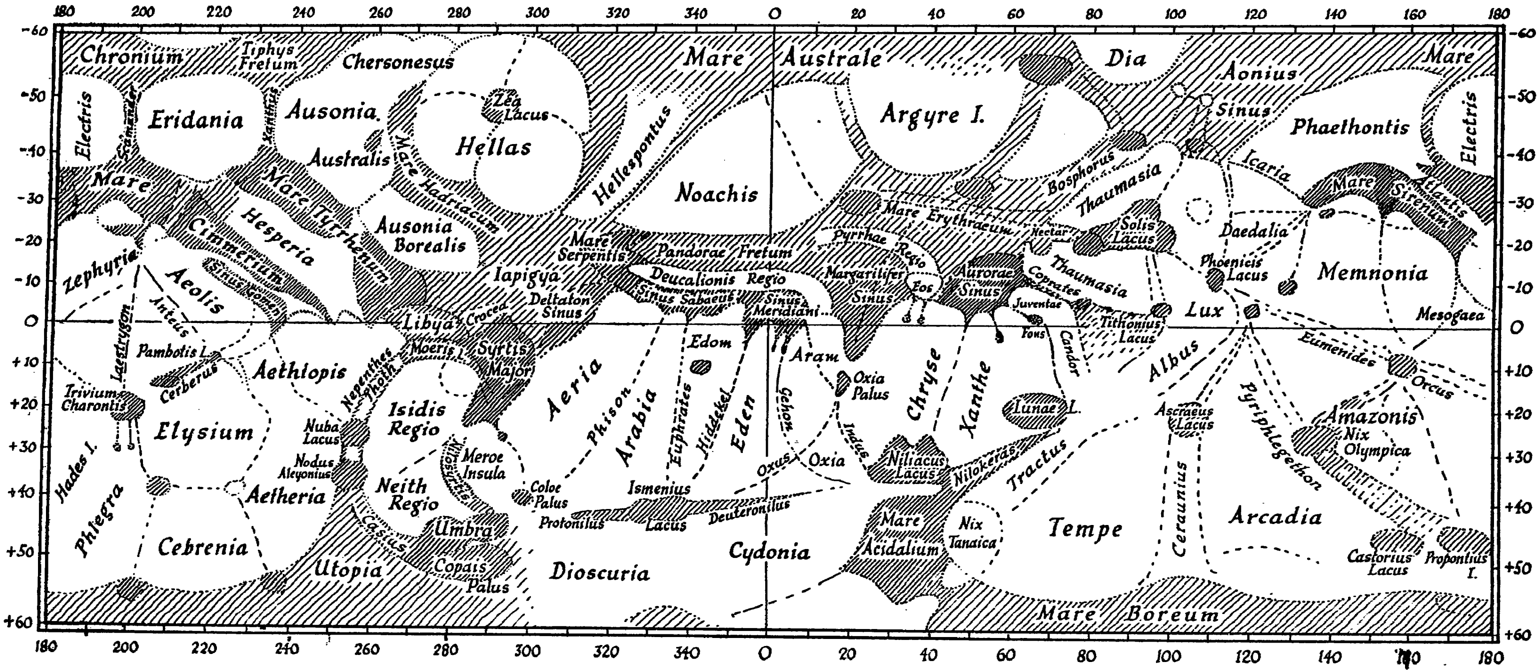
—the polar caps are certainly very thin, and in no way comparable to the thick permanent beds of the ice-fields of the Earth.

We have already observed, from the unequal brightness of its different regions in the spring, that the bed is not uniformly thick; in addition the average diffuse reflecting coefficient, or proportion of light reflected (the 'Albedo'), is clearly feebler than that of a thick bed of snow, about 0.5 against 0.8, and consequently it is certain that the snow can never cover the ground thickly and completely; indeed, it must be very thin. We can calculate the thickness by consideration of the heat the snowy areas receive from the Sun and the time they take to disappear; we find it to be from 0·1 to 10 inches—we cannot be more precise because we have to take into account some still imperfectly known elements. For instance, whether the polar caps can properly be said to be formed of snow, whether they are thin ice-beds more or less covered with hoar-frosts as the Russian astronomer Tikhoff supposed after a study of his photographs of 1939, or whether, as some have gone so far as to say, they are simple beds of hoar-frost, can scarcely be said with any certainty; though the comparisons made by Tikhoff between his photographs of Mars and photographs of snowy or icy surfaces strongly favour the hypothesis of a cap composed of ice, an idea supported recently by the Russian astrophysicist Scharonow following a photometric study of his 1939 photographs.

If we have devoted considerable space to the detail and discussion of the polar caps and phenomena associated with them, it is because we cannot doubt that their existence and evolution are of fundamental importance in

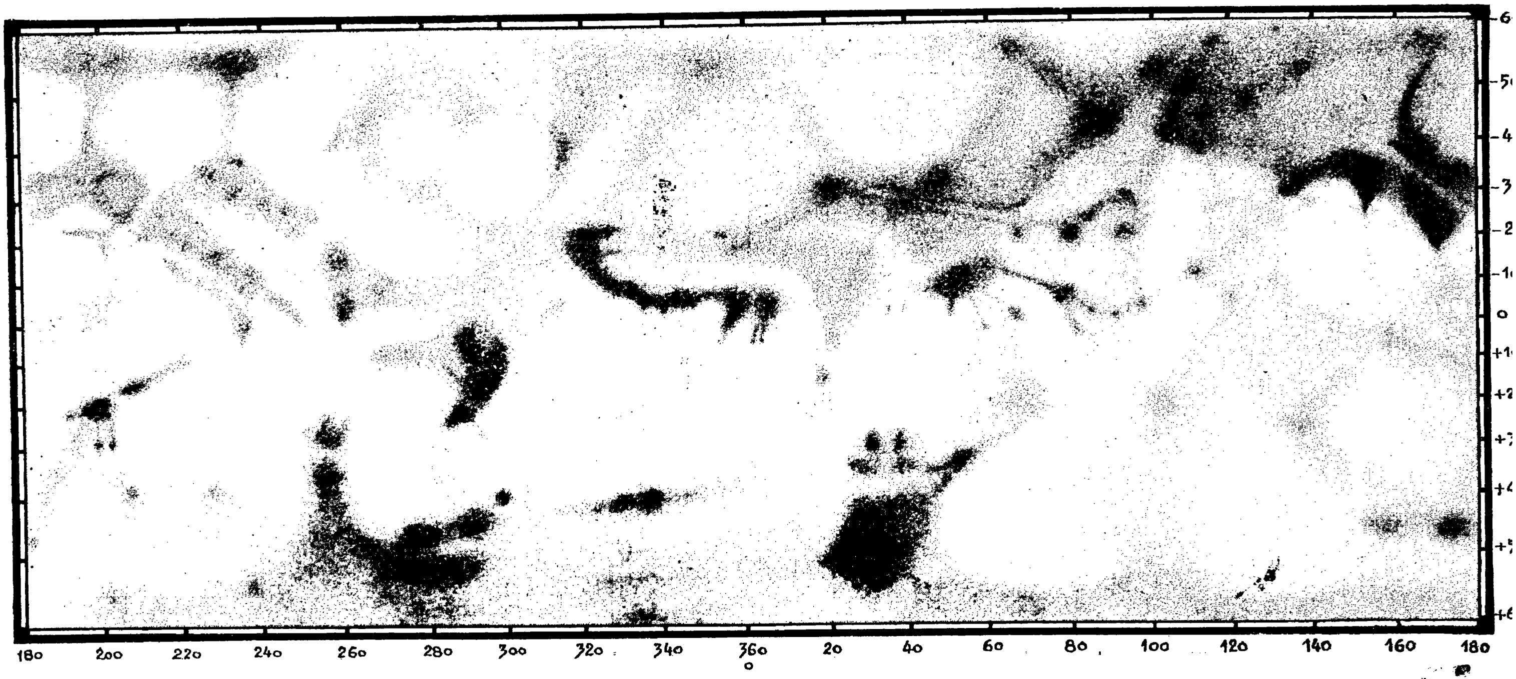
understanding most of the other Martian phenomena—which, as we shall see, appear often enough to be closely connected with the seasonal variations of the polar caps, and give us the strongest reasons for believing in the existence on Mars of the three states of water—solid, liquid and gaseous—in which nearly everybody agrees in seeing the key, if not to the entire Martian problem, at least to most of the essential parts of which it is composed.

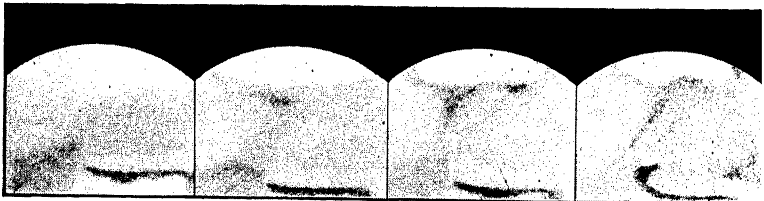
Nomenclature of the Principal Details of Martian Topography.



MAP OF MARS

Constructed principally from visual and photographic observations made in 1939 and 1941 by Slipher, at the Bloemfontein Observatory (South Africa); Lyot, Camichel and Gentili, at the Pic du Midi; and the author, at Le Houga Observatory.





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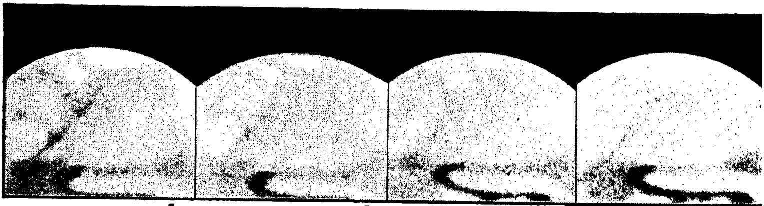
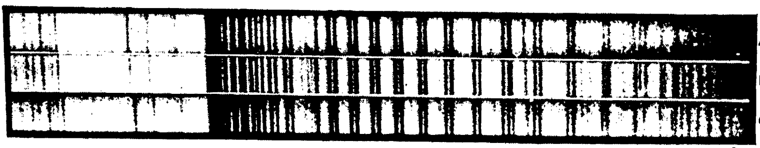


$\eta: 0°$ 5 $\eta: 30°$ 6 $\eta: 60°$ 7 $\eta: 90°$ 8



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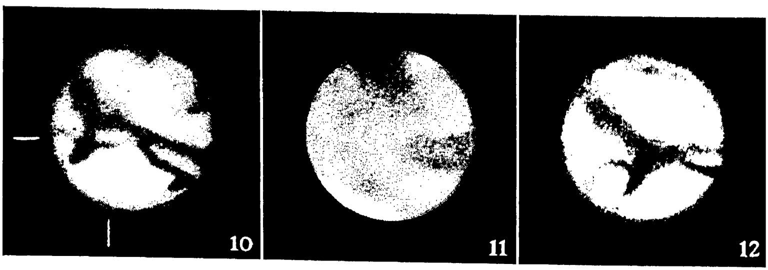


PLATE II

1 to 8. *Cycle of Seasonal Variations of the South Polar Cap of Mars.* During the winter (η=200°) the cap forms under a cloudy mantle. At the end of winter (η=250°) the newly-formed cap still appears dull. During the course of spring (η=300° and 330°) it diminishes little by little and breaks up; brilliant promontories appear and the cap becomes encircled by a dark fringe. By the beginning of summer (η=0°) part of the cap has disappeared, and the remaining fragment decreases rapidly. During the summer (η=30° to 60°) the cap continues to diminish slowly, and becomes very small. At the beginning of the autumn (η=90°) whitish clouds appear in the polar zone; they rapidly develop, and extend greatly during the autumn and winter. The cycle then recommences.

9. *Absence of Oxygen in the Atmosphere of Mars.* The spectrum of Mars reveals no component of Martian origin, as would be revealed by the Doppler–Fizeau Effect by the side of the doublets due to terrestrial oxygen.

(A) Spectrum of Mars, taken when the planet was approaching the earth at a speed of 22 mi./sec.

(B) Spectrum of the Sun, shown for comparison.

(C) Spectrum of Mars, taken when the planet was receding at 20 mi./sec.

(W. S. Adams and Theodore Dunham, Mount Wilson Observatory, 1933.)

10 to 12. *Photograph of a 'Yellow' Cloud in the Atmosphere of Mars.* This cloud, very brilliant visually, was still plainly visible on photographs taken in infra-red light (10), but did not appear in photographs taken simultaneously in ultra-violet light (11), 2nd November 1926. The cloud had disappeared by the following day (12).

(Photographs taken by W. H. Wright at the Lick Observatory, California.)

THE BRIGHT REGIONS OF MARS

The bright regions, which cover about two-thirds of the planet's surface, are of a beautiful rosy or orange colour, and are responsible for the ruddy tint so characteristic of Mars when seen with the naked eye.

Save at a few special points, these regions are monotonous, and show, in general, great regularity both in colour and in surface brightness.

The Desert Hypothesis

For a long time these regions have been considered to be sandy deserts comparable to our Sahara, or more generally, let us say, bare zones covered with a dust more or less coloured by metallic salts such as iron oxide Fe_2O_3, whose red colour is well known.

This theory was first advanced on account of the diffusion factor of these regions, which is in the neighbourhood of 0·15 to 0·20, that is to say, comparable to reddish-brown stones and about the same as the average of our coloured deserts (which range from about 0·10 to 0·25).

We can thus easily interpret their permanence and general monotony, as well as their colour—rose in places, ochre in others, even brownish at a few points.

Its fits in also with the absence of any marked general relief which observations attribute to the greater part of the planet. If high, well-marked mountain chains existed, such as the Alps, we ought to observe irregularities of the terminator (boundary between light and darkness) when

Mars shows a phase, since, as is well known, high summits are touched by the sun before the lower-lying plains beneath. We can see this very well upon the Moon with binoculars or even with the naked eye, and, as has been noted, seeing the Moon with binoculars is more or less equivalent to seeing Mars through a really good instrument.

Such deformations of the terminator have been seen from time to time, but they always behave as temporary apparitions and often move a hundred miles or so from one day to another, thus clearly showing that they are of an atmospheric and cloudy nature.

If there are any mountains on Mars they can scarcely exceed five or six thousand feet in height, and must be more like ancient plateaux than well-marked chains of massive peaks in sharp relief.

Yet we must mention that, at certain epochs and at certain times, and always in the same positions, whitish spots are seen in the rosy regions; they are sometimes very brilliant, and are considered by some to be isolated summits covered with snow, hoar-frost or clouds.

The hypothesis of dusty deserts gives at least a satisfactory explanation of certain atmospheric disturbances that we sometimes observe, in the form of yellowish clouds that for several days hide, more or less completely, the topographical details beneath—just as sandstorms would do.

Polarimetric Observations

At last, this interpretation has been supported by modern polarimetric research.

Polarization of Light. Let us rapidly recall that

light should be considered as a train of transverse electromagnetic vibrations, perpendicular to the luminous ray; in natural light, for example that sent to us by the Sun, the vibrations are at random and occur in all directions round the ray; but if we reflect the ray, under a suitable incidence (57°) on a sheet of glass, we can show, by means of a polarimeter, that the vibrations of the reflected ray have been turned in a single direction perpendicular to the plane of incidence; we then say that the light has been rectilinearly polarized, the plane of incidence being termed the plane of polarization. Whatever be the angle of incidence, we observe a mixture of natural and polarized light, in various proportions.

All bodies which reflect or diffuse light can cause a more or less marked degree of polarization; this power is dependent, in a very complicated fashion, upon the constitution, structure and brilliancy of the bodies concerned, and by examination and analysis of the polarization produced we can sometimes recognize them.

An additional difficulty is that the proportion of polarized light is frequently very small, and thus difficult to determine.

Observations of B. Lyot. However, thanks to his particularly sensitive polarimeter, a French astrophysicist, Dr. B. Lyot, was able to measure with precision, between 1922 and 1928, the polarization of light from the Moon and the principal planets; he paid special attention to Mars, and drew curves giving the proportion of polarized light as a function of the angle of phase Earth-Planet-Sun. He then tried to reproduce experimentally, in his laboratory, the polarization curves obtained for the bodies; for the Moon he found that a mixture of grey and

brown volcanic ash furnished him with an absolutely similar curve, and the lunar surface seems therefore to be covered with ashes and dust of this kind.

Moreover, his observations showed that the polarization curve of Mars is precisely similar to that of the Moon, at least for that part of it which can be observed (it is limited to an angle of 47°, as the phase of Mars never exceeds this value), and in consequence, says Dr. Lyot:

'It looks as though there exists, on the surface of the Martian continents, a dusty cover analogous to that which covers the lands of the Moon.'

In the course of these measures he also had occasion to observe the yellowish clouds, which, he has said, have a very characteristic action on the polarization of Mars inasmuch as they diminish it without betraying their own nature—confirming that they are altogether different in character from the ground material; he notes, however, that some whitish spots on the edge of the disk, on the sunrise side, show a polarization comparable to that of hoar frost.

Lastly, the radiometric observations made by the American physicist W. W. Coblentz in 1924 and 1926, to which further reference will be made later, enabled him, according to a recent revision (1942), to detect in the infra-red spectrum of Mars the emission band lying between 8 and 10 μ, characterizing silica compounds.

Summarizing, we can therefore conclude that the desert theory of the planet's bright regions seems to have a great deal to recommend it, and is founded upon a great many concordant observations.

THE ATMOSPHERE

The presence of an atmosphere around Mars has been known for a long time, but the positive data concerning it are of recent acquisition.

Chemical Composition

To begin with, is this atmosphere—whose existence cannot possibly be questioned—truly analogous to our own, as has been believed for a long time?

INDIRECT METHODS. There are several means of defining the chemical composition of a planetary atmosphere.

First, the kinetic theory of gases, which teaches us that the gas molecules are moving at great speeds, increasing according to the lightness of the gas; thus the average velocity of the heavy molecules of carbon dioxide gas is in the region of a quarter of a mile a second, whereas that of the light hydrogen molecules is about 1·2 miles a second (at about 0°C.), but these speeds are only an average, since some molecules move more slowly, others faster.

Now the attraction of a planet can only hold a molecule in its atmosphere up to a certain speed called the Speed of Escape, dependent upon the pull at the planet's surface; this critical speed is 7·2 miles per second for the Earth, but only 3·1 miles per second for Mars. Consequently the most rapidly moving molecules escape little by little, and the famous English astrophysicist Sir James Jeans has observed that a planet cannot long re-

tain in its atmosphere gases whose speed of motion exceeds one-fifth of the velocity of escape.

We can thus be certain that (save an improbable continuous renewal) the lightest gases, hydrogen and helium, have long since disappeared from the atmosphere of Mars.

In addition certain very active gases cannot long be retained in a free state, due to their chemical properties; such are the Halogens (Cl_2, Br_2) and a good number of the gaseous oxides (NO_2, ClO_2, CO) and also ozone (O_3), if it comes in contact with the ground.

SPECTROGRAPHIC ANALYSIS. But the most direct method is evidently spectral analysis of the planet's light. The light coming from the Sun and diffused by the planet's surface twice passes through the Martian atmosphere—once going and once coming back—before reaching us. Consequently the spectrum of Mars ought to show absorption lines due to the gases of its atmosphere—if, of course, such lines are to be found in the accessible portion of the spectrum—in the same way that the spectrum of Venus shows up carbon dioxide, and those of the great planets ammonia and methane.

For the long period when observations were made visually or by inaccurate procedure, spectrum analysis furnished contradictory results—but during the last fifteen years it has become certain that the spectrum of Mars shows no characteristic lines of this sort. Important results have been obtained, however, concerning oxygen, water vapour and carbon dioxide.

Here a difficulty arises at once, because these substances are abundant in our own atmosphere and imprint their absorption upon the spectra of all heavenly

bodies; how then can we detect the lines produced by the small quantity of gas in the atmosphere of Mars?

This difficulty has been overcome thanks to the Doppler-Fizeau effect, which is as follows: when a source of light is in motion relative to the observer, its spectral lines are slightly displaced from their normal position; towards the red if the source is receding, towards the violet if it is approaching.

Now because of the relative movements of Mars and the Earth, the speed of approach or recession can at certain times (near the Quadratures) become sufficient for this effect to be detected; and in consequence the characteristic lines of Martian oxygen, for example, ought then to be displaced to one side or other of the fixed lines due to the oxygen in our own atmosphere.

However, this method remained impracticable for many years due to the predicted minuteness of the displacements; and it was not until 1933 that the American astrophysicists W. S. Adams and T. Dunham, using some particularly powerful apparatus combining a very high dispersion spectrograph with the largest telescope in the world—the 100-inch instrument of the Mount Wilson Observatory in California—arrived at some conclusive results.

Absence of Oxygen. Under these conditions they have obtained, with exposures of several hours, large-scale spectrograms on which the Martian lines ought to be completely separated from the lines due to terrestrial oxygen; but no such lines have been found on their plates (Pl. II, 9) despite a careful study by the most sensitive microphotometer, so that they have been able to say definitely that in the atmosphere of Mars there is not a

hundredth, nor even a thousandth, of the oxygen present in ours; and doubtless the true amount is much less even than this.

Practically, therefore, oxygen is absent from the atmosphere of Mars.

The German-American astrophysicist R. Wildt has suggested in this connection that, taking into account the feeble atmospheric pressure prevailing on Mars, a layer of ozone, formed under the action of the Sun's ultraviolet radiation—such as that found high above the Earth—accumulated on Mars at the level of corresponding pressure, in the immediate neighbourhood of the surface; it then, on account of its great chemical activity, energetically oxidized the planet's crust; the ozone thus used up was formed again at the expense of oxygen, and thus the oxygen supply was rapidly exhausted.

This hypothesis agrees well with what we saw earlier with regard to the probable richness of the Martian deserts in oxides of iron.

Scarcity of Water Vapour. Following these investigations on oxygen, Adams and Dunham attacked, in 1937 and 1939, the problem of water vapour. Here also their spectrograms, which should have completely separated the terrestrial from the Martian lines, showed none of the latter; and it is thus clear that the Martian lines cannot attain so much as 5 per cent. of the intensity of the terrestrial ones.

However, we should not conclude that water vapour is totally absent from the atmosphere of Mars. In the course of these measures the spectrograph was directed towards the centre of the disk, that is to say, towards the bright red regions (which are the most luminous) which we

recognize as deserts; we have therefore no real reason to be surprised that spectrographic search for Martian water vapour bands has been unsuccessful. We cannot draw up arguments to oppose the conclusions founded on all the wealth of phenomena shown by the polar caps; we should see here only a confirmation of the accepted ideas of the great general dryness of the planet.

DISCOVERY OF CARBON DIOXIDE. Thus, spectrographic analysis had until recently accumulated only negative results; but very recently, in 1947, the Dutch-American astronomer G. P. Kuiper, at the McDonald Observatory (Texas) has succeeded in detecting the presence—in small quantity, it is true—of carbon dioxide CO_2, which is so abundant in the atmosphere of Venus, but which had previously escaped discovery in that of Mars.

This achievement has induced him to make a fresh attempt to detect water vapour in the Martian polar regions; this attempt is proceeding at the present time. Although he has not yet succeeded in this, a by-product of the search has been the discovery of the infra-red bands of water ice in the spectra of the polar caps, early in 1948.

PROBABLE COMPOSITION. Then what may be the main permanent gases making up the Martian atmosphere?

Certainly gases undetectable spectroscopically, sufficiently heavy, and not too active chemically (as has been shown above).

These eliminatory conditions mean that we have a clear choice between nitrogen and the rare gases, argon, neon, etc.; and as these last are—as their name suggests—very scarce, it appears that the Martian air is likely to be

composed mainly of nitrogen—which, incidentally, makes up at least $\frac{4}{5}$ of our own. To this we must now add a small amount of carbon dioxide, roughly twice that which exists in the terrestrial atmosphere.

Physical Structure

The atmosphere presents a very remarkable physical structure, whose properties have been revealed by photographs obtained through coloured filters isolating particular colours—violet, blue, green, yellow, orange, red and even ultra-violet or infra-red.

Simultaneous photographs of this sort present very different aspects—the yellow pictures show the planet much as one sees it visually; the same familiar details are represented with far greater contrast in the red pictures, but vanish in the green, and the blue and violet pictures no longer present even the same general aspect; the familiar details disappear, to be replaced by very different ones. (Pl. III, 1–2.)

THE VIOLET LAYER. These phenomena are not due, as was at first thought, to any particular properties of the Martian soil, but originate in the planet's atmosphere; this must be so because on certain occasions spots on the surface of the planet remain visible even in the blue pictures. (Pl. III, 3–6.) These cases of exceptional transparency prove also that the power of diffusion and the usual great opacity of the Martian atmosphere are not essentially due to its permanent gaseous constituents, but rather to an absorbing and diffusing layer suspended in the atmosphere, which could be made up, says the American astronomer Slipher:

'of an enormous quantity of finely divided matter hav-

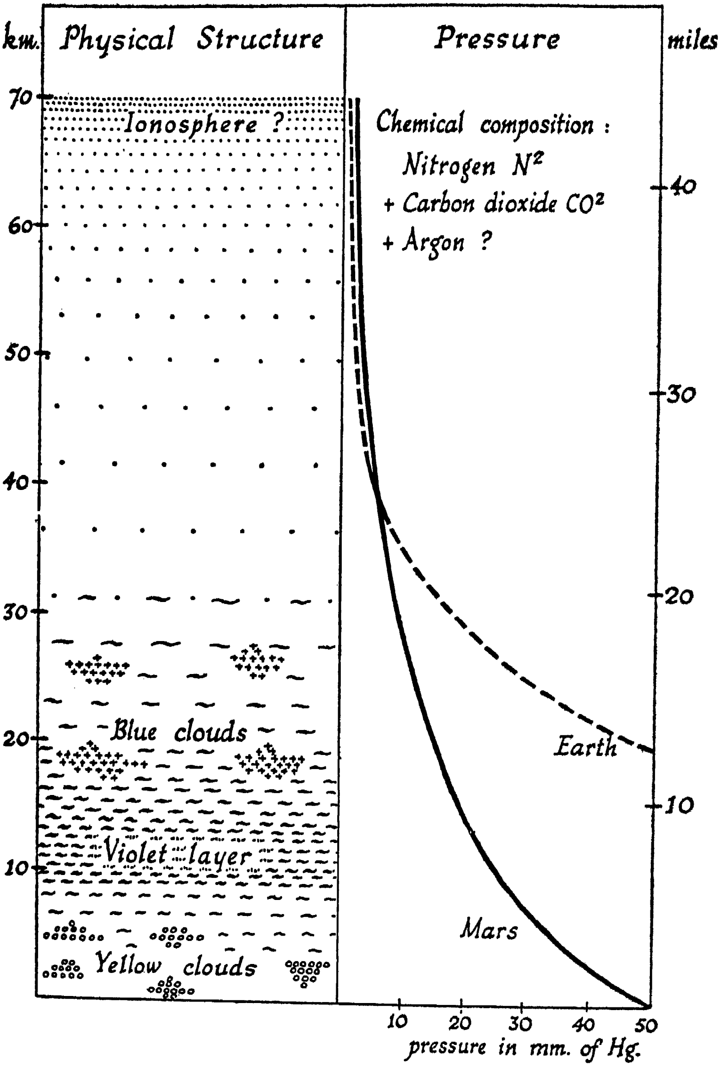


Fig. 2. Summary of the present state of knowledge concerning the atmosphere of Mars.

ing an astonishing power of diffusion and absorption of short-length waves, and which at rare intervals only becomes clear enough to let the short waves penetrate to the surface and come out again afterwards.'

As for the matter making up this layer, which we shall call briefly the 'Violet Layer', thin clouds of fine ice-crystals have been suggested; but to be truthful the nature of this dust remains totally unknown, and its variations unaccounted for.

Clouds

THE TWO MAIN KINDS. It has been known for many years, from visual observations, that the clouds of the planet Mars are of two main kinds: (1) whitish clouds, and (2) yellowish clouds.

The examination of photographs taken in light of different colours by Wright and others fully corroborates this. Clouds of class 1 are visible in violet light and become invisible in red; these are by far the most apparent on the photographs. Let us call them briefly 'blue clouds'.

Those in class 2 are visible in red light and become invisible in blue; let us call these clouds 'yellow'.

The visual and photographic results are thus in complete agreement concerning these two kinds of clouds, whose displacements from day to day sometimes permit us to determine the speeds of the Martian winds. These winds are always very feeble—2 to 4 m.p.h. at the most—but the wind-chart of the planet is still very rough.

Now, what can be the composition of these clouds?

YELLOW CLOUDS. We have seen that the yellow veils could well be clouds of sand or dust raised in the deserts, but it is difficult to believe, with the feeble speeds ob-

served for the winds, in powerful sandstorms of a violent nature, extending over much of the surface of the planet and lasting for several months—as have occasionally been seen. It has been suggested that they might be clouds produced by active volcanoes; such clouds have been known on the Earth extending for immense distances and persisting for months, but can we picture active volcanoes on a planet so dried-up as Mars, when nearness to the sea is known to be essential to the activity of ours?

Blue Clouds. As for the bluish-white clouds, we can easily attribute them to polar mists or light veils of fine ice crystals like our cirrus; but it is undoubtedly an exaggeration to compare them purely and simply to our aqueous clouds of liquid droplets and to advance the theory that it may even sometimes rain on Mars, because from an observational point of view their diffusion factor —which rarely exceeds 0·4—is greatly inferior to those of our dense clouds of such a kind, which are nearer 0·7; and theoretically such an explanation can no longer be easily accepted by reason of the very low pressures that must prevail at the great heights where the blue clouds appear. The hopes placed in studies of polarization have not so far been realized; all that has been proved is a great diversity in behaviour and therefore in constitution.

Optical Properties. In reality, all serious attempts to penetrate the physical nature of these clouds remain premature so long as their optical properties have not been quantitatively defined. In this respect, the photometric determinations that I made at Le Houga Observatory in 1939 have enabled me to obtain several indications as to the latter; they show that these cloudy veils are usually very transparent (transmission factors observed,

40 to 95 per cent) and feeble diffusing agents (diffusion factors observed, 2 to 10 per cent). In fact, dense clouds analogous to ours are certainly very rare exceptions on Mars; and in any case the great rarity of the atmosphere should only allow it to support feeble condensations of extremely fine particles.

Levels. When these clouds arrive at the terminator they produce characteristic deformations, often very curious. From these deformations we can theoretically deduce, without difficulty, their heights above the ground; thus we have obtained about 2 to 3 miles for the yellow clouds, 6 to 19 for the blue. The latter are clearly the higher, as has frequently been determined directly, because they can remain visible when the yellow clouds hide the surface of the ground.

As, on the photographs, the violet layer hides the yellow clouds and lets us see the blue, no doubt the most absorbent part is more or less situated between them at an intermediate level, let us say in the region of 5 to 10 miles.

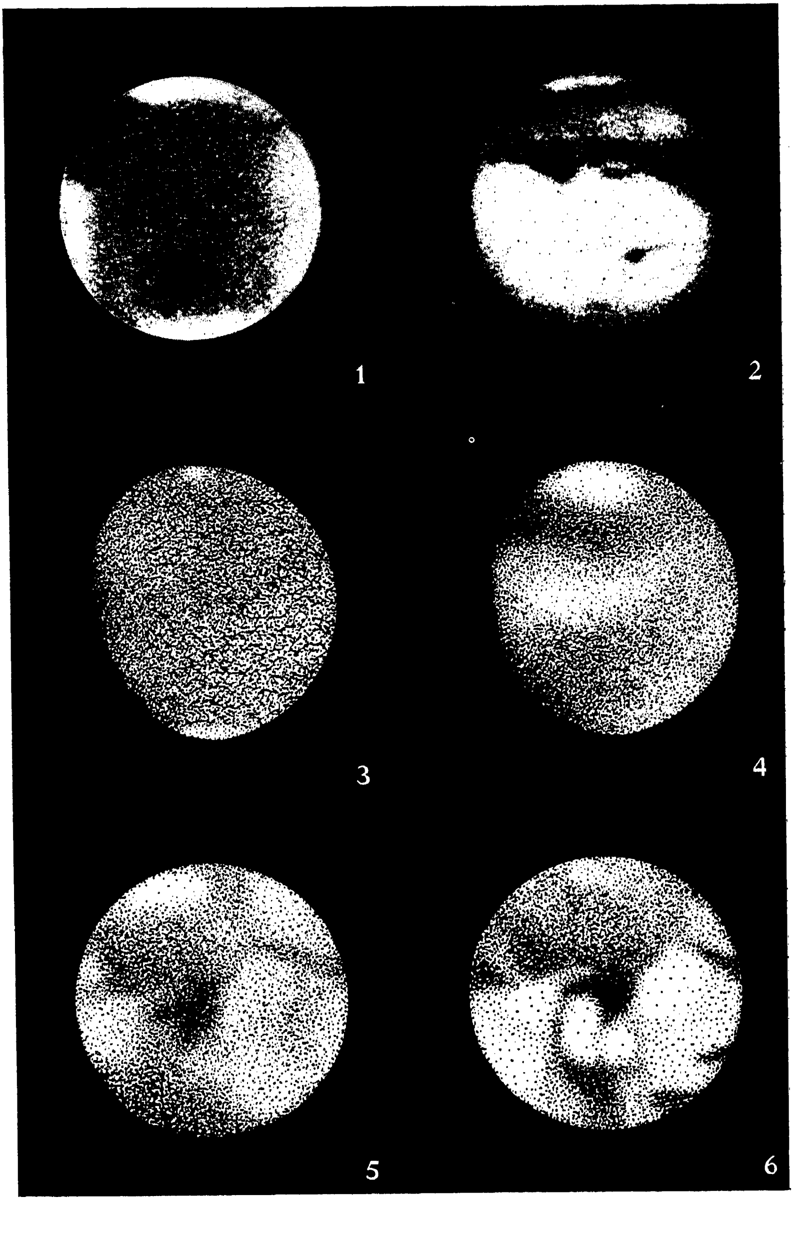
Various Phenomena. Following up the examination of the photographs, we notice very strongly that while the green, yellow and red pictures clearly show the snowy polar caps—less brilliantly in the red, of course, because of their colour—the caps often appear more extended and less well defined on the blue and violet pictures, which, as we have seen, reveal the atmospheric haze. This peculiarity must certainly be attributed to the haze and to the light mists which, especially in spring, spread very generally over the polar regions; and thus it is not the cap itself which is registered in violet, but rather the atmospheric formation which surmounts it. Later, in summer, this veil

PLATE III

1 and 2. *Photographs of Mars in Ultra-Violet and Infra-Red Light, 29 July 1939.* These two pictures present nearly all the characteristic phenomena described in the text. The picture in infra-red light (2) shows the spots on the surface and the intense darkness of the disk near the edge. The ultra-violet picture (1) shows the disappearance of these spots under the opaque veil of the 'Violet Layer', here uniform at the centre of the disk but reinforced by a blue cloud of ClassI at the E. (left) limb, where it is the end of the afternoon; the polar mist on the more northerly (lower) regions in autumn and the fog surmounting and bordering the South Polar cap, then in spring, are shown; and on the W. (right) limb the setting Sun raises a diffuse arc that dissipates in the morning. (After photographs by W. H. Wright at the Lick Observatory, California.)

3 and 4. *Normal Aspect of the 'Violet Layer' in the Atmosphere of Mars.* (3) Violet Layer uniform and opaque, 24 September 1926. (4) Violet Layer opaque, but with bright condensations (Class I clouds), 20 April 1937. (After photographs taken in blue light by E. C. Slipher at the Lowell Observatory, Arizona.)

5 and 6. *Unusual Transparency of the Violet Layer in the Atmosphere of Mars.* On 20 May 1937, the pictures obtained in blue light (5) showed the surface details nearly as clearly as those obtained in yellow light (6). Compare with 3 and 4, which show the same region of the planet. (After photographs by E. C. Slipher at the Lowell Observatory, Arizona.)


1
2
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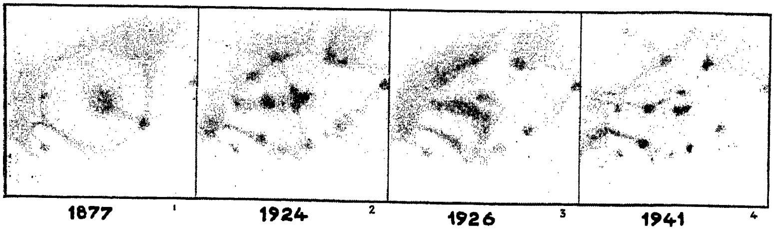
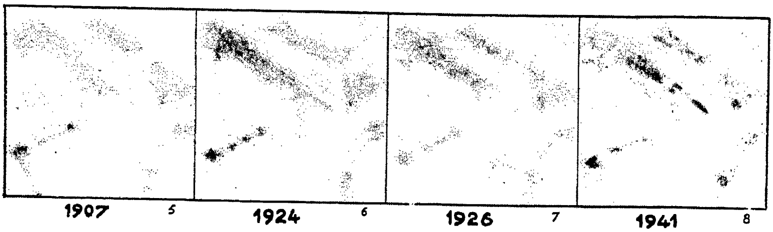
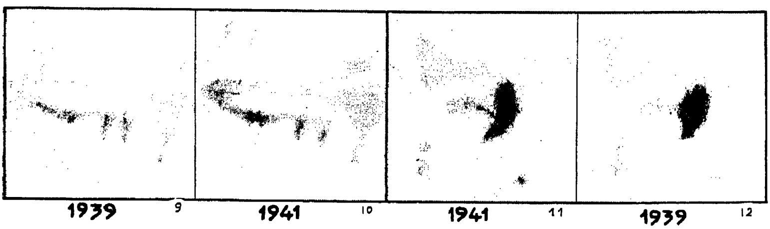
Region of Solis Lacus



Region of Mare Cimmerium



Mare Serpentis Pandoræ Fretum Syrtis Major



Region of Hellespontus

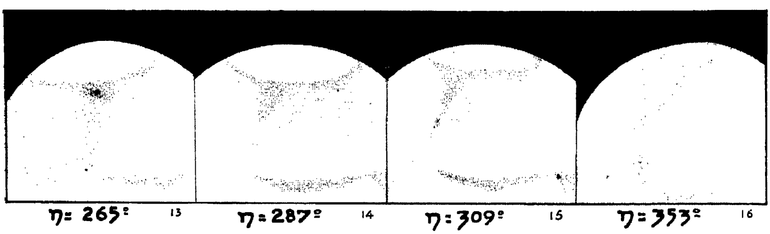


PLATE IV

1 to 4. *Changes in the Solis Lacus.* During three-quarters of a century the Solis Lacus has on several occasions undergone

extraordinary transformations, particularly in 1877–9 (1) and 1926–8 (2, 3), but modification of detail is constantly occurring here, as will be shown by a comparison of 2 and 4 relative to 1924 and 1939–41.

5 to 8. *Variations in the Region of Mare Cimmerium.* This region of Mars also presents frequent transformations, which are not, however, periodic; a comparison of 5 to 8 will give an idea of these.

In 1907, great development of the Pambotis Lacus and the canals Cyclops and Cerberus II, which diverge here. In 1924, development of a darkened zone on Æthiopis at the end of September. In 1929, fading of the Tritonis Sinus, enormous development of the Nepenthes-Thoth (compare with 5) and appearance of a great dark lake near Hephæstus. In 1941, development of a great dark zone on Æolis on the border of Mare Cimmerium (already in 1937–9); nearly complete invisibility of the Pambotis Lacus (compare with 5 and 6).

9 and 10. *Irregular Seasonal Variations in the Region of Mare Serpentis and Pandoræ Fretum.* The shadowy band of Pandoræ Fretum and the dark area Mare Serpentis are frequently invisible or very feeble during the southern winter (9); they generally develop in the course of the spring and often become very intense during the summer (10). (See also Plate II, 1–8.)

11 and 12. *Seasonal Variations of the Syrtis Major.* The great dark area Syrtis Major is generally broad during the greater part of the Martian year (12); it appears to become narrow near perihelion by more or less marked brightness of its eastern portion, the light frontiers of Libya and Isidis Regio being seen at this epoch as promontories in half-tones (11); this aspect often lasts for a great part of the southern summer.

13 to 16. *Seasonal Development of a Dark Flow in the Region of Hellespontus, during the Southern Spring of Mars.* At the beginning of the winter, a very dark spot forms at the border of the south polar cap. This spot extends progressively towards the north and diminishes in intensity during the first part of the spring. By the middle of spring it has taken the form of a long track following the W. border of the great light island Hellas, and reaches to the tropical zone. It does not progress much further, but its thinning appears to continue until the end of the spring and it then seems to prolong an old rift of the polar cap. (See Pl. II, 2 to 5.)

disappears, and the reduced polar cap appears clearly. Moreover, during the winter, when the cloudy veils under which the cap re-forms cover the polar regions, the veils are well recorded in violet light and not at all in red—a supplementary proof of their atmospheric nature and great tenuity.

Let us finally note that the violet pictures show in general a luminous arc on the sunrise side, which is, according to the American astronomer W. H. Wright, 'probably due to condensation during the night', because this glimmer dissipates progressively during the Martian morning.

Influence of Solar Activity? We must finally draw attention to a recent note by the French geophysicist P. Bernard, in which he compares 'the atmospheric perturbations of the Earth and Mars', characterizing the first by the microseismic agitation measured in Europe (due to the depressions of the polar front in the North Atlantic), and the second by the temporary clear regions enumerated for many years at the Jarry-Desloges Observatory at Sétif, ending with this conclusion: 'The atmospheric perturbations of the planet Mars occur simultaneously with those of the terrestrial atmosphere,' each depending upon solar phenomena in relation to the 11-year cycle of activity of the Sun.

More thorough researches will no doubt be necessary before we can unreservedly accept such a correlation—somewhat unexpected, but not inconceivable. Confirmation will be of the highest importance in the interpretation of the atmospheric phenomena of the two planets.

The Atmospheric Pressure

Let us now deal with a most important element in the understanding of Martian phenomena; the atmospheric pressure.

Until very recently, it was only possible to guess at this pressure; the value generally accepted has been in the order of $\frac{1}{10}$ atmosphere, although much higher values have been proposed.

PROCEDURE OF ESTIMATION. Physical methods have at last given an experimental basis for these estimates, and even if the values obtained are still rather inaccurate these methods and their first results are well worthy of close attention.

A first method utilizes the powers of diffusion of the whole of the planet in yellow light and in blue light, that is to say, the visual and photographic albedos, since the atmosphere ought to affect each in some way. The American astrophysicist D. H. Menzel, in 1926, thus arrived at a pressure inferior to 5 cm. of mercury. Unfortunately, his hypotheses do not in general apply to Mars, owing to the special properties of the 'violet layer.'

A second method uses the visual polarimeter; it consists of a comparison between the polarization of the light of Mars (of which polarization the atmosphere should produce a part) and that of the Moon (which is certainly devoid of an atmosphere). In this way Dr. B. Lyot, in 1929, obtained a pressure inferior to 1.8 cm. of mercury. Unfortunately, he was forced to make use of some very uncertain elements, and some very questionable assumptions. Very recently a young observer, A. Dollfus, working at the Pic du Midi with the Lyot polarimeter

during the 1948 apparition, produced better evidence for a pressure of the order of 6 cm. of mercury.

A third method uses heterochrome photographic photometry, and consists in studying the variation in colour over the planet's disk—since this must be affected by the amount of atmosphere intervening. On this basis the Russian astronomers Barabascheff and Semejkin, in 1933, obtained a pressure of 3·7 cm. of mercury. Unfortunately, they put forward a theory of these phenomena that seems to be highly dubious, and their measures also may be seriously in error.

Another Russian astrophysicist, W. Scharonow, has deduced from his 1939 photographs a pressure of 9 cm. of mercury, but by a process that is—as he himself admits—very indirect and of a highly speculative character. A more refined analysis of Scharonow's 1939 photographs has been made by one of his co-workers, Miss Sytinskaya, who gives as the final result of the measurements a pressure of 8·4 cm. of mercury.

Finally a fourth method, analogous to the preceding, uses visual photometry, and consists in studying how the brightness of spots on the planet varies according to the distance from the centre of the disk—since the thickness of the interposed planetary atmosphere varies according to this distance. The observations I made at Le Houga Observatory in 1939 enabled me thus to obtain a pressure in the region of 7 cm. of mercury; but this result is not much more certain than the others, because visual determinations of brilliancy are always subject to grave errors.

PROBABLE PRESSURE, AND CONSEQUENCES. To sum up: the atmospheric pressure on Mars is still imperfectly

known, but appears to be in the region of 2–2·5 in. of mercury near the ground, that is to say, $\frac{1}{15}$ of ours.

This is nevertheless a very important result, because this value is greatly superior to the maximum tension of water vapour (pressure of saturated vapour) at normal temperatures, and consequently if there is any water on Mars it can remain in the liquid state so long as the temperature does not rise above 40° to 50°C.

This pressure, 2–2·5 in. of mercury, is the same as that prevailing in our atmosphere at a height of about 13 miles—the lofty stratosphere; let us notice, however, that since the force of gravity is much feebler on Mars the pressure diminishes less quickly as we ascend, and thus at altitudes greater than 25 miles the pressure of the Martian atmosphere should be, curiously enough, greater than that of our own at the same level. This helps us to understand the great heights attained by the clouds on Mars, and also why the winds, associated, of course, with variation and differences of pressure, are very moderate.

We can also try to understand how the solar radiation is filtered by the atmosphere of Mars; but this would carry us too far here, and we will only repeat that the atmosphere is very transparent to long light-waves, becoming very opaque after the green; while, at the violet end, part or all of the ultra-violet rays fail to reach the surface of the planet.

Let us now consider a question to which modern research, mainly in American observatories, has brought—in the course of the last twenty-five years—a particularly interesting response; that of the temperatures which prevail on the surface of the planet, about which we were formerly reduced to making vague theoretical calculations whose results seemed to be contradicted by the visual observations.

The Thermocouple

Let us first recall the principles of measuring the temperature of an inaccessible object, since it is naturally impossible to transport a thermometer to Mars—so far, at least!

We know that all heated bodies emit energy in the form of electro-magnetic radiation. When the temperature is very high, this radiation includes visible light, as is the case with electric lamps and with the Sun; when the temperature falls the radiation includes a greater and greater proportion of infra-red light. At ordinary temperatures all the radiation is infra-red, but it exists none the less, and can still produce appreciable heat. From the energy sent by the radiation we can deduce the temperature of the source; if we can transform this energy into heat it only remains to make accurate measurements of it. When the energy is great and the heat considerable, we can employ a thermometer; but when the amount of energy

is small we must abandon the thermometer and have recourse to more sensitive methods, such as the thermocouple. This apparatus is founded on the phenomena of thermo-electricity, the principles of which are as follows: if we form a circuit with two wires of different metals soldered end to end, and then warm one of the two joins, an electric current is set up in the circuit, which we can detect and measure with a galvanometer.

It is therefore possible to deduce accurately the temperature of a body whose radiation falls on one of the soldered joins, thanks to the galvanometric measurement of the electric current set up by the difference in temperature. This important result has many practical applications.

The method is theoretically simple, but it is not so easy when we come to measure the temperature of the planet Mars, which sends us only a very minute quantity of heat. Even then, in this feeble radiation still further reduced by the absorption of our atmosphere, we have yet to separate the part due simply to diffused solar light from that which represents the personal contribution of the planet. This is possible since the former is made up mainly of visible light and the latter completely of infra-red. We use for this purpose either filters made up of sheets of glass, fluorine or rock salt, or a water cell.

Finally, having overcome all difficulties, the American astronomers Pettit and Nicholson, at the Mount Wilson Observatory, and Menzel, Coblentz and Lampland at the Lowell Observatory, with their great telescopes associated with very delicate thermocouples constituting equipment of extraordinary sensitivity (capable of detecting variation in temperature of a hundred-thousandth

of a degree), succeeded, in 1922, in obtaining the first direct determinations of the temperature of Mars, afterwards obtaining (during 1924 and 1926) measures for the different regions of its surface.

This was, we must admit, a great triumph and a marvellous achievement.

Temperatures, Diurnal and Seasonal Variations

And here are some of the main conclusions to be drawn from their results.[1]

The mean temperature of Mars, owing to its greater distance from the Sun, is lower than that of the Earth, about $-20°$C to $-30°$C against our $+10°$C.; but we ought not to conclude that Mars is a frozen world. Indeed, its various regions naturally show very different temperatures.

At the centre of the disk, that is to say at noon in the equatorial and tropical zones, the temperatures clearly exceed $0°$C. and are in the neighbourhood of $+10°$C. to $+20°$C. in the bright regions, and of $+20°$C. to $+30°$C. in the dark regions, where temperatures even exceeding $+30°$C. have been observed. The Martian ground can thus attain quite a high temperature.

On the contrary, the atmosphere must be very cold; in particular the clouds of high altitude, the 'blue' clouds, are, naturally enough, at very low temperatures of from $-40°$C. to $-60°$C., very similar to the temperatures prevailing in our own stratosphere.

[1] The figures cited are principally founded on the measurements of Coblentz in 1926. Perihelic opposition. At aphelic oppositions, Mars being farther from the Sun, the temperatures are lower by twenty degrees. Note also that these temperatures refer to the sunlit surface; those of the atmosphere and of the unilluminated regions should be lower by thirty degrees.

These clouds, whose presence it is easy to recognize on the photographs taken in violet light, have a very characteristic influence; when they are visible, the observed temperatures are very low and descend to near $-40°$C.; on the contrary, when the Martian atmosphere is clear and transparent, the temperatures registered under the same conditions are only from $0°$C. to $-20°$C.

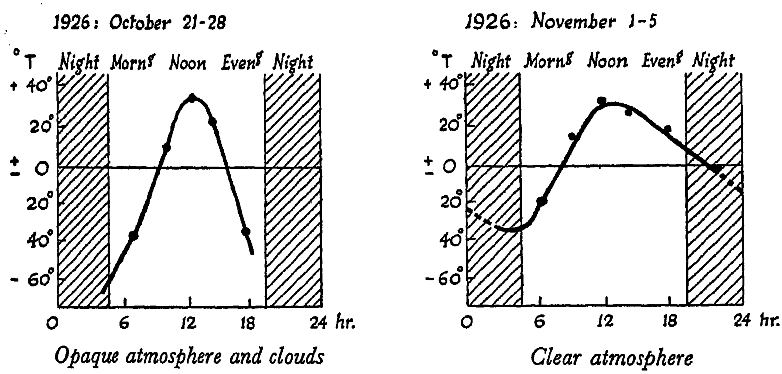


Fig. 3. Diurnal temperature variations in the southern tropical regions of Mars near mid-summer of the southern hemisphere, according to the radiometric measurements of W. W. Coblentz at the Lowell Observatory in 1926.

These remarks are necessary if we are to interpret satisfactorily the curve of diurnal variation of temperature (Fig. 3).

Nevertheless, it appears pretty certain that, even at the equator, the nights are very cold, as would be expected from the thinness and dryness of the atmosphere.

These observations allow us also to define the influence of the seasons, carrying the measures successively from north to south of the disk. We prove thus (Fig. 4), that near the Polar Circle in winter the temperature (at noon)

is in the neighbourhood of -40°C. when clouds hide the surface, but only -20°C. when it is not concealed; naturally, the temperature must descend very much lower in the unobservable regions plunged in the polar night, perhaps to -90°C. or -100°C., sensibly lower than on the Earth.

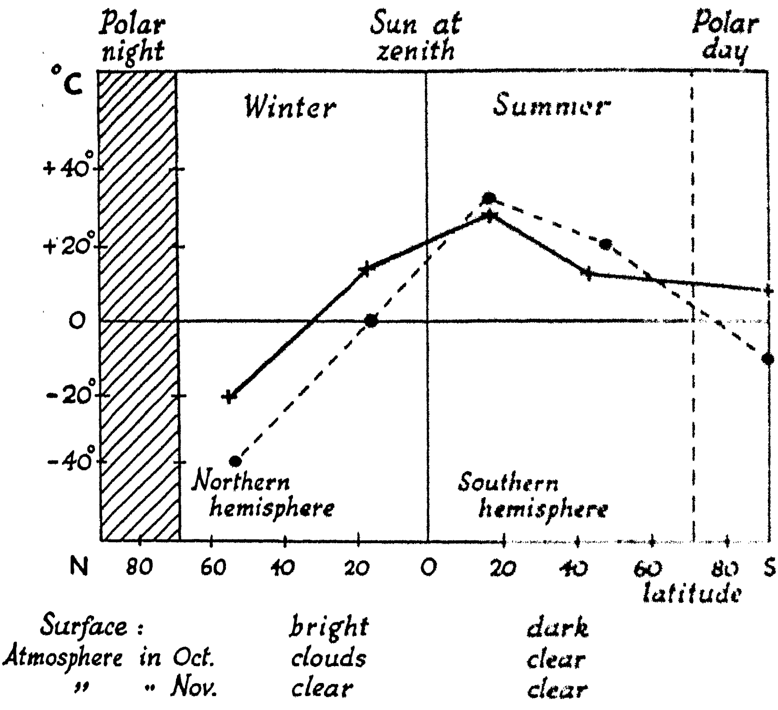


Fig. 4. Seasonal variation of temperature at local noon on Mars, according to the measurements of W. W. Coblentz in 1926.

In the temperate regions in winter (referring, as usual, to noon) the temperature borders on -10°C. to 0°C., rising to $+20^{\circ}$C. at the equator. In the other hemisphere, where it is summer, the temperature attains a maximum of about $+30^{\circ}$C. in the tropical zone, descending to about

$+20°C.$ in the temperate zone, and falling back to about 0°C. in the polar regions. Even if we do not take into account the small residual polar cap, it is certain, says Coblentz, that 'the South Polar region is without doubt much warmer than is indicated by the measures, and should be from 5°C. to 20°C., perhaps more'.

Certainly, at the beginning of the southern summer in 1924, temperatures of −50°C. to −70°C. were recorded there, but it seems very probable that we were actually recording the temperature of the 'violet' cloud at that moment covering the surface snow, stopping the planetary radiation; and indeed this interpretation of the surface radiation is, according to Coblentz, a verification of the presence in the atmosphere of water in the form of crystals or vapour. We know indeed that water vapour energetically halts a good percentage of infra-red radiation, producing a well-known 'greenhouse' effect.

We can finally conclude that the climates of Mars are not very different from those of the Earth, and only a little more rigorous on the average; but that the variations in temperature from day to night and, in the polar regions, from summer to winter, are much more pronounced; also we can justly say that the Martian climate is of an exaggerated continental type.

THE DARK REGIONS OF MARS

We can now begin a study of the dark regions which form characteristic permanent patterns on the surface of the planet, and which can be identified without difficulty on the detailed chart (Pl. I).

Irregular Variations

An attentive study shows, however, that these permanent regions undergo certain modifications of detail of various kinds; some extrinsic, caused by the interposition of atmospheric veils (the clouds examined earlier), others, on the contrary, intrinsic, capable of developing and persisting for months and years, and definitely affecting the true surface of the planet.

We can divide these variations into two main categories.

The first are purely irregular; they consist of a change in brightness of a more or less extended bright region—generally bordering on a dark area—which, at a given moment, darkens rapidly as though the adjacent dark region had encroached upon it; then, after having persisted for several years, this abnormal darkening disappears and the region regains its former aspect. These changes have been observed in various places, but certain regions are particularly subject to them; such is the area of the Solis Lacus, which manifested important changes first in 1877–9, then in 1926–8 (Pl. IV), and that of the Mare Cimmerium, which has presented important

zones of extension on its NW. shore at different times in the past (1800, 1924, and in 1937 to 1946). (Pl. IV, 5–8.)

Seasonal Variations

But other variations, perhaps more interesting for the interpretation of the phenomena of the planet, are those which recur, often very regularly, in the course of each Martian year; the seasonal variations.

These variations often manifest themselves in different forms which have been progressively recognized, but whose mutual relationships remain to be defined.

LOCAL CHANGES. A first form of these variations consists, like those we have just seen, in the extension, followed some months later by the retreat, of certain patches on the neighbouring bright regions; for example, that which occurs regularly in the Syrtis Major dark area. This patch is narrow towards the end of the spring, and during all the southern summer—as was the case during 1909, 1926 and again in 1941; it then extends little by little towards the east, and encroaches on the neighbouring region between Libya and Mœris Lacus during the autumn and southern winter—thus we saw it in 1905, 1907, more recently in 1935, 1937 and 1939; but by the return of the southern spring, the patch has left the invaded regions and become narrow once more. These phenomena recur with a regularity sufficient for us to be able to predict them more or less correctly—as Antoniadi has done—and we can forecast accurately the appearance of the patch at different epochs of the Martian year. But this regularity does not seem perfect, and may be either in advance or retard of the seasonal cycle of the polar cap. (Pl. IV, figs. 9 to 12)

CHANGES OF COLOURING. But a relationship obviously connected with the seasonal evolution of the polar cap manifests itself with regard to the changes of colour of these patches, detected in 1894 by the Americans Lowell and Douglass, but much better defined by the observations of E. M. Antoniadi with the 32-inch telescope of the Meudon Observatory during the close approach of 1924.

During this year, near the middle of the southern spring, when the polar cap was in full retreat, this observer saw develop around it a brown band which extended from day to day, and gained ground in all directions northward. This replaced the former colours of the dark regions, grey, greenish or bluish, which turned one after the other to brown or chocolate tints, even violet or carmine—proving at the same time a great diversity in constitution. At the end of the southern spring, and during the summer, these changes of colour even included the equatorial plains.

Thus we have witnessed the extension of a 'something' that is born in the polar regions during the melting of the snowy cap and spreads in all directions, causing the changes of tint in the dark regions—and more or less in certain regions between them, though some of these appear refractory and keep a uniform tint throughout the year.

Altogether, these observations suggest some phenomenon whose development in a dried-up world is caused by the arrival of the water provided by the melted snow of the polar cap.

CHANGES OF INTENSITY. But this is not all; other variations occur, perhaps more subtle and apparently still more closely dependent on the annual evolution of the

polar caps—no longer concerning the form or colour of the spots but simply their intensity, their degree of darkness, which also changes in a very characteristic fashion. This phenomenon, detected originally by Lowell, has since been defined very precisely—in particular by M. G. Fournier, in France, who describes it as being really a succession of phenomena:

'At the start of the melting of the white material (that is to say, at the beginning of spring) the circumpolar "seas" are extremely dark and sometimes even blend with the dark fringe round the cap that they exaggerate. . . .

'As the spring advances, the dark shading progressively encroaches from the pole towards the equator across the seas. This advance, across wide expanses and along channels, takes place at a variable speed, but nearly always very rapidly; a few weeks only suffice to change the landscape completely. Great dark tracks (always in the same places) are seen forming over the dark areas; their emersion points are almost always gulfs (which exist at the dark border of the polar cap).'

The most remarkable of these dark tracks is certainly that which develops in the region of the Hellespontus, observed in 1894, 1907, 1924 and anew in 1939; we see there a very dark spot formed at the border of the south polar cap at the end of the winter near lat. 55°, extending towards the north and stretching as far as the tropical regions near the middle of the spring, progressing regularly from the pole towards the equator at about 11 miles per day, according to my observations of 1939. (Pl. IV, 13 to 16.)

But let us continue with M. Fournier's description of the

appearances observed; indeed, what we come to next is equally interesting:

'. . . the outlines of the seas are definite and clearly marked, shaded in the main, without nevertheless assuming a uniform tone; at the same time as the temperate and sub-tropical regions alter, the circumpolar zone grows paler; and the seas become smaller and vanish, as though emptied of their dark contents. At this time (that is to say, at the beginning of the summer) appear the lands which, liberated a short time previously from beneath the mantle of white materials, have remained until now drowned in the sombre element thus issued. This lasts until the end of the autumn, and we can observe it so long as the atmospheric masses accumulated do not mask the region and drop the curtain on the scene. . . .

'The winter comes . . . the great sombre areas lose their colour, and their outlines again appear indefinite.

'But in the planet's other hemisphere, following the same rhythmic cycle with a lag—or an advance—of half a Martian year, the same succession of phenomena takes place, modified only by the differences in topographical structure.'

Such is the description given by M. Fournier after thirty years' continuous observation of the phenomena of the seasonal variations in intensity of the dark areas; phenomena which do not, as we know, present the perfect regularity that one might deduce from the above description—which, for the sake of clarity, is rather schematic.

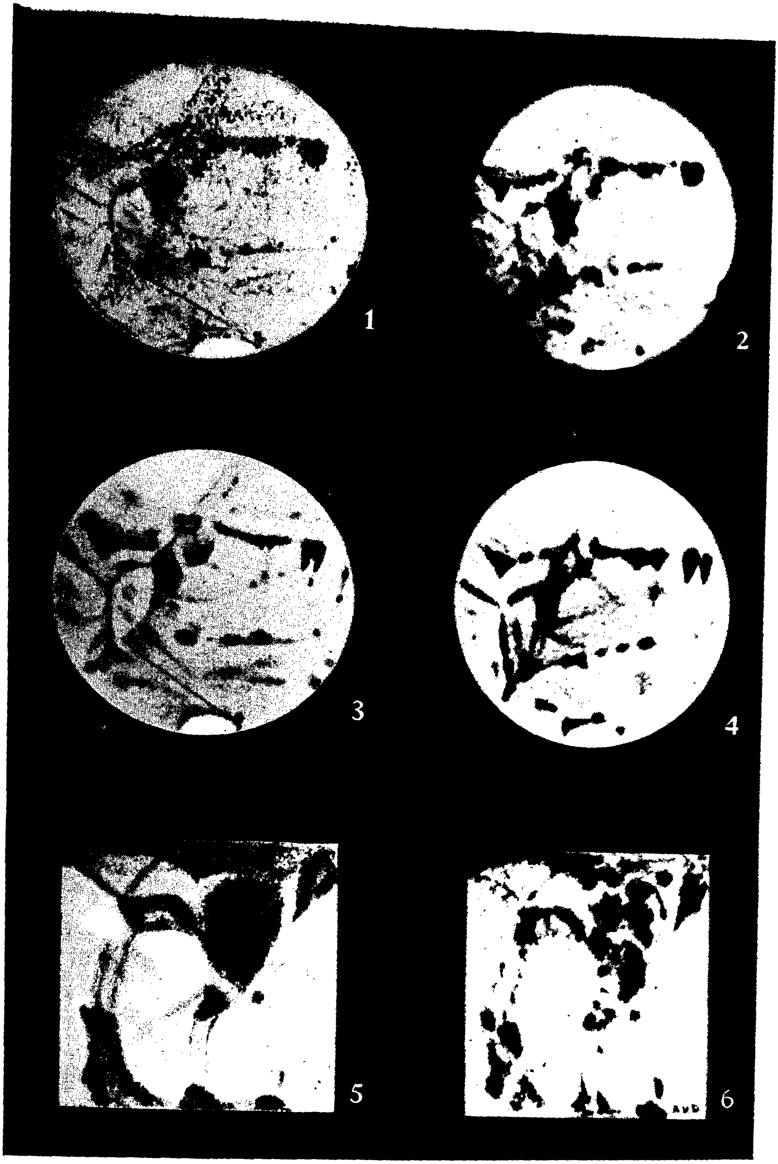


PLATE V

1 to 4. *A Laboratory Experiment on the Canals of Mars.* A large-scale drawing simulating the planet Mars (1) has been observed by two experienced observers (3, 4) through an optical system

(continued on back)

duplicating the conditions of an actual observation of the planet with a medium-sized instrument, and then photographed at some distance under the same conditions of resolving power. Here all the drawings are reduced, and the photograph enlarged to the same scale. A careful examination of these pictures gives some valuable hints about the fine structure of the so-called 'canals' of Mars.

5 to 6. *The Canals of Mars as seen with a Large Aperture.* These two drawings of the Syrtis Major area were made by A. Dollfus, at the Pic du Midi Observatory, in February 1948, with the 24-inch telescope and a magnification of 900.

The left-hand drawing (5) shows the 'canals', some single, some doubled, some broad and pale, some narrow and dark, but all seemingly continuous, as seen when the 'seeing' is good, but not perfect; the right drawing (6) shows how they are disintegrated in minute, irregular spots, their course looking broken and ragged, when seen under perfect conditions of seeing. Note that the dark areas are also resolved into minor components

The Agent Causing the Seasonal Variations, and its Means of Propagation

Here, then, are phenomena which seem strongly to suggest some activity bound up with the flow provided by the melting of the polar ice.

But is it quite certain that these variations are truly an indication of the arrival, in the affected areas, of water flowing from the polar regions?

Indeed, the hypothesis has long been regarded with doubt by many people on the grounds that, Mars being slightly flattened at the poles, it is difficult to conceive that liquid water could spread out of its own accord from the poles towards the equator, that is to say recede from the centre of the planet and thus rise against the force of gravitation.

It might perhaps be possible to discover the forces necessary for this to happen in the phenomena connected with capillarity, and using this to explain the observed appearances; 'a circulation of a liquid element . . . in a crude manner, by capillarity or porosity' (Fournier), because the dark flows such as that of the Hellespontus, described above, strongly suggest a liquid stream; according to the observations made at the Jarry-Desloges Observatory in 1924 this appears to be in direct topographical relationship with the basins and fissures of the polar cap.

Some time ago, however, it was suggested that if there is any liquid water on the ground the lowest parts of the atmosphere ought to be distinctly humid, and that consequently the phenomena observed might only indicate the arrival of water vapour diffused in the atmosphere or carried by aërial currents.

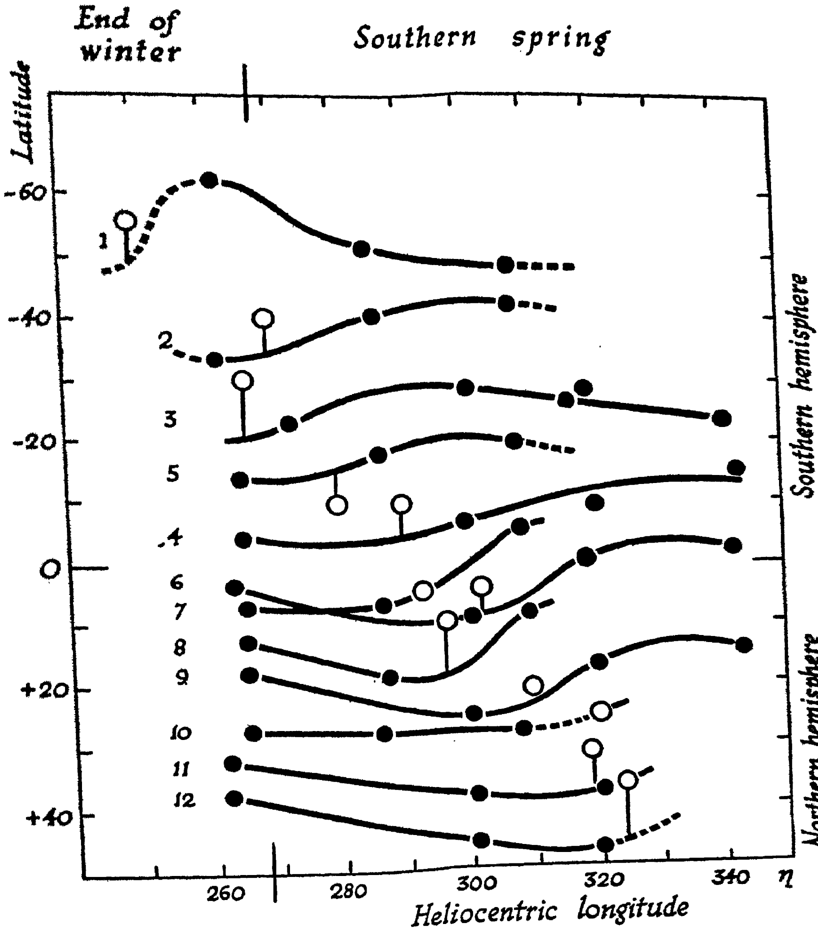
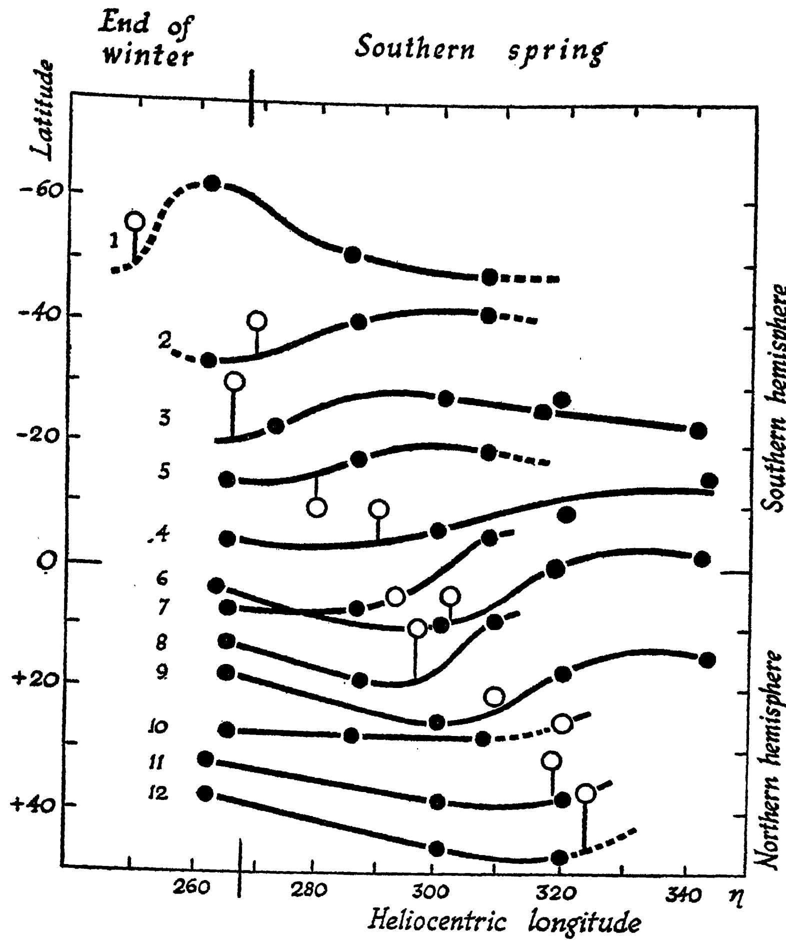


Fig. 5. Propagation of a seasonal wave of darkening coming from the South Polar regions of Mars during the southern spring, according to the observations of the author at Le Houga Observatory in 1939.

Each curve gives, plotted at the areographic latitude of the investigated area, the variations of darkness observed in it between the heliocentric longitudes $\eta=260°$ to $\eta=340°$.

1. Depressio Hellespontica; 2, Hellespontus; 3, Mare Sirenum; 4, Auroræ Sinus; 5, Sinus Sabæus; 6, Ganges; 7, Euphrates (South); 8, Syrtis Major; 9, Lunæ Lacus; 10, Euphrates (North); 11, Nilokeras; 12, Niliacus Lacus.



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This idea is in good accord with what we know about the phenomena of evaporation and sublimation which, at the low pressures prevailing on Mars, assume a vital importance unknown in terrestrial nature; it also accords better with the speed of propagation of 28 miles per day (1·2 miles per hour), which cannot possibly be explained by the slow circulation of the liquid by capillarity. Nevertheless, we can perhaps invoke the presence of such a mechanism in the cases of the dark tracks, whose rate of expansion (11 miles per day, or about half a mile an hour) is, perhaps, sufficiently slow.

This, then, is a general outline of what close study has revealed as to the complex phenomena of the great dark areas of the planet.

Nature of the Dark Regions; the Vegetation Hypothesis, and Difficulties

But we must now try to explain these phenomena, and ask ourselves what is the nature of the surfaces of these dark regions.

Now, since the maritime theory was rejected, nearly a century ago, we have been accustomed to regard these areas as being covered with vegetation more or less analogous to our own. This hypothesis certainly gives an excellent reason for the seasonal variations in colour of certain patches; the changes from green to brown, it is said, resemble those of our forests, green in spring but reddish in autumn. As to the permanence of other spots, it is pointed out that our prairies, or grasslands, are green throughout the year. The theory also interprets very well the seasonal wave of darkening bound up with the diminution of the polar cap, because in a greatly dried-up

world the vegetation would be very sensitive to variations of dampness. This dampness, condensing during the winter in the polar regions, would only give the vegetation a chance of development by its arrival in the spring. To explain fully the irregular darkening of certain desert regions, temporary fertility would have to be invoked. The temperatures are, as we have seen, high enough to support vegetation, and the dark areas are the warmest.

For these reasons, most astronomers consider that the existence of vegetable life upon the surface of our neighbour planet is well established, and during modern times the idea of Martian vegetation has been so generally accepted that it may seem strange to question it.

However, there are some difficulties in the way of the vegetation hypothesis.

There can be no doubt that it is the general greenish colour of the areas which has suggested this hypothesis, and this coloration is still often cited as an argument in its favour. But the reason that our plants are green is that they are pigmented by chlorophyll. Now, two facts seem to oppose the existence of this substance upon Mars. For one thing we know that the terrestrial grassland appears luminous in infra-red, in consequence of the high reflective power of chlorophyll in this region (Wood); but nothing of the kind appears in the infra-red pictures of Mars, where the dark patches are, on the contrary, particularly obscure. For another thing, the almost total absence of oxygen in the Martian atmosphere seems to be a very serious objection, as we know that the function of chlorophyll in our plants is to free this gas; indeed, some people are driven to ascribe to chlorophyll the origin of nearly all the free oxygen in our terrestrial atmosphere.

It is well to note, in passing, that the analogy has been forced, because our plants turn reddish in the dry season and grow green again with dampness, whereas the supposed vegetation on Mars turns brown with the arrival of moisture (in any case the change-over to brown appears to be distinctly irregular); and though we can always hold the theory together by introducing supplementary hypotheses (for example, the progressive adaptation of plant life to keep up with the disappearance of oxygen has been invoked), it might perhaps be as well to see first whether any other explanation, not making use of vital activity—and thus simpler in some ways—cannot be found, involving only mineral physiochemistry.

After all, what is to be explained is only the colorations and their changes with dampness. The well-known Swedish physiochemist Arrhenius suggested many years ago the presence of rocks charged with metallic salts—whose great richness of colour we know—and hygroscopic substances; but it does not seem that the theory has been investigated deeply and it has not obtained much support, although it has been revived in recent times by the French geophysicist A. Dauvillier.

Nevertheless, it will suffice if we remember that the vegetation theory is not the only one which has been propounded to interpret the phenomena of the dark areas of Mars, and it is premature to consider the question definitely settled.

The feeble luminosity of the dark areas makes true physical methods of investigation, such as photometric or spectrophotometric observations, very difficult; and these methods have not yet been able to furnish any positive results in this connection.

THE CANALS

We have now seen how the main features of the planet have been surveyed, and how, despite the many uncertainties that remain, the results obtained enable us to make up a reasonably coherent picture of the phenomena displayed on Mars.

But we must now deal with the 'canals' of Mars—since we must call them by their name. . . .

The Discovery of the Canals: Schiaparelli

The conventional designation 'canal' was applied by the Italian astronomer Schiaparelli to certain lightly drawn and more or less regular bands discovered by him with the 9-inch telescope of the Milan Observatory in 1877, but which, it may be pointed out, can be traced on the sketches of earlier observers. This in itself was not extraordinary; but during the following years these streaks, confirmed elsewhere by many other observers, became more regular, narrower, even straighter and more and more numerous, so that maps of Mars eventually took up a strange and unnatural aspect that ended by suggesting that the term 'canal' was perhaps more than a conventional designation. His observations, followed up with a more powerful instrument of 18½-inch aperture, became even stranger because not only did his canals take on this thin, straight aspect but many of them doubled at certain epochs, and, where he had previously seen a single canal, appeared, sometimes from one day to

the next, two parallel lines separated by upwards of 50 miles; this is called the 'gemination' of the canals.

A Strange Story: Lowell

These statements, more or less laboriously confirmed at first, were enormously developed, extended and co-ordinated from 1894 onwards by the American, Lowell, and his assistants, who at Flagstaff, under the limpid and calm sky of a high desert region of Arizona, accumulated some dozens of thousands of observations of the planet, first with a refractor of 24", then with a reflecting telescope whose aperture was 42". With Lowell the map of Mars became a true cobweb; the planet showed itself to be covered with an inextricable network of single or double canals whose number grew unceasingly, reaching 400 by 1900 and nearly 700 by 1909—since they were no longer confined to the continental zones, but invaded the dark regions as well. Without going into all the details recorded at the Lowell Observatory as to the appearance of the lines and their extreme fineness—fixed at only a mile or two in breadth—or the systems which they form, the circumstances of their gemination or their behaviour in the dark regions, we must however mention the numerous dark spots observed at their intersections—christened 'Oases'—which have diameters of several miles, their seasonal variations being bound up, as are the variations of the great areas, with the evolution of the polar caps.

In 1906 Lowell advanced, from his observations, some rather unexpected hypotheses. Here are his principal conclusions: the network of canals and oases proves by its geometric, artificial and co-ordinated aspect to be the work of living beings, endowed with powers of reasoning

—let us say, 'Martians'—who have been able, in their already very dried-up planet, to organize rationally the circulation and distribution of the water provided by the seasonal melting of the polar caps, water being indispensable to all vital activity. That which we call a 'canal' is not the true channel—which is too thin to be seen from here—but rather a band of irrigated land which extends for some distance on either side, such as the Nile valley in the middle of the Egyptian desert. As soon as the polar snow melts in the spring, the water is pumped into the canals, and the vegetation develops on their borders and in the oases; if one canal does not suffice a second, parallel to the first, is opened to the liquid. We can thus account for the appearances recorded, the seasonal variations and the geminations.

Such were the ideas of Lowell.

However, despite confirmation by some other observers, the strangeness of the appearance, the fantastic pace of the phenomena raised from the first a more and more violent opposition, which did not agree in any way with the fairy-tales told by Lowell.

Difficulties

Indeed, though they did not speak of canals on the other planets, Schiaparelli, but more definitely Lowell and his assistants, published drawings of Mercury, Venus and the satellites of Jupiter equally covered with geometrical patterns; canals seen double by one observer remained at the same moment single to Schiaparelli; on Lowell's drawings the canals seemed too narrow and certain doubles too close to be truly revealed by his telescope; and finally, some excellent observers could scarcely

see the network of canals at all, whilst others drew them with very small instruments.

All these disquieting facts showed that there was something 'not quite right' in the representation of the canals of Mars.

In fact, as early as 1879 the Englishman Green had noticed that these canals were often drawn at the boundary between two discontinuous shades in these regions; the Italian Cerulli—who drew, nevertheless, a large number of canals—noticed about 1896 that certain stretches of them sometimes resolved into more or less aligned spots, an idea developed in 1903 by the Englishmen Evans and Maunder; a number of children, entirely ignorant of the question, were shown disks representing Mars, devoid of canals but with a few details (filaments and spots) drawn in, and produced drawings covered with straight lines very similar to the fine canals.

Also numerous were those who came to consider, with Green, that these canals were only stylized representations of the limits of half-tones, or with Cerulli that the lines glimpsed were due to a trick of the eye 'due to dark elements spread lengthwise'; and Maunder, in 1896, reasonably concluded that 'we cannot pretend that what we can just distinguish is really the ultimate structure of the body we are examining', and thus that the famous canals may be simply 'the sum of many complex details'.

As for the double canals, the geminations, most authorities now consider—after having examined a number of more or less satisfying optical theories to explain their appearance—that they are purely and simply illusions.

All this has not been settled without interminable discussions on the optical and physiological phenomena

occurring at the limit of visibility, and even on the comparative power of large and small instruments, because—strange as it may seem at first sight—certain astronomers question whether large telescopes reveal more than small, because they are more subject to the disturbances of the image produced by atmospheric turbulence.

Europe Condemns the Canals: Antoniadi

During the very close approaches of 1909 and 1924 Antoniadi obtained some very conclusive results with the great 32-inch telescope of the Observatory of Meudon.

This excellent draughtsman, who had previously glimpsed the linear canals when using a telescope of only 9½-inch aperture, saw in the large instrument, he says: 'the rectilinear canals vanish, though very delicate details, inaccessible to the telescopes of Schiaparelli and Lowell . . . were obviously and continually visible.'

The general aspect of his drawings appears to be confirmed by the photographs taken at the same epoch with very large instruments, including those of Lowell—whose drawings, on the other hand, differ greatly. Antoniadi, having accumulated various arguments against the true existence of the canal network and asserted in a most peremptory fashion the crushing superiority of large instruments, came to the firm conclusion, reaffirmed in 1930—as always until his death in 1944—that 'the great telescope of Meudon enabled me to settle once and for all the canal question. Here is the real explanation:

'Nobody has ever seen a true canal on Mars, and thus the more or less rectilinear canals of Schiaparelli, single or double, do not exist either as canals or as geometrical lines; but they have a basis of reality, since all are situated

either on a continuously spotted irregular track, a rugged grey border, or an isolated and complex patch.

'Indeed, the whole surface of Mars presents this infinitely irregular natural structure.'

As to the actual nature of the surface, Antoniadi was satisfied with the hypothesis of Sahara-like deserts.

These definite statements have been corroborated by numerous observers, using very large instruments.

So in recent years the general opinion has been as follows: the canals of Mars do not exist—they are illusions created by inadequate instruments, and vanish when studied with powerful apparatus. This is more or less the 'official' theory in Europe, and has been widely spread by popular writers.

The Americans Defend Them: Slipher

It is necessary to add 'in Europe', because opposite opinions are often met with in America, where, on the contrary, people quote the theories of Lowell, the set of reports by Pickering, the observations of Trumpler with the great 36-inch telescope of the Lick Observatory which still covered the planet with canals during the 1924 opposition, and the observations made at Mount Wilson by Pettit in 1939. The following categorical statements are made by Slipher, affirming in 1921 that:

'the photographs of Mars made at the Lowell Observatory furnish the objective certainty . . . of the existence on the surface of the planet of a network of dark rectilinear lines—the "canals"—and of small black spots—the "oases";

'that these linear tracks are sensibly continuous and uniform from one end to the other;

'that the canals have an individuality with reference to each other, some being broader and darker than others;

'that the canals extend directly from one point to another, and never come to an abrupt halt;

'that in numerous cases where canals cut each other, each continues exactly to follow its own path;

'that some of the lines are adjacent and parallel—the double canals—and that the separation of these differs;

'that moreover the majority of the canals which have been observed visually at the Lowell Observatory have been repeatedly registered on a great number of photographic plates made in the course of the last fifteen years, and finally that the extensive visual observations made at the Observatory have been confirmed as a whole—as well as corroborated in detail by the photographs.'

It has seemed useful to cite these observations of Slipher's in full, as he again reasserted them in 1931 and 1940, stating that the results accumulated at the Lowell Observatory only served to enhance them. Many American astronomers hold similar views, and are in complete disagreement with those of the European school of thought.

A Subtle Appeal: Fournier

Even in France some observers continue to follow the views of Schiaparelli, if not those of Lowell; in particular M. G. Fournier, in 1939, returned to the question in an effort to re-establish on this side of the Atlantic the idea of linear formations on the Martian surface. Here are his main points:

He recalls first—and with sound reason—that nobody has denied that minute detail exists on the Martian con-

tinents, more or less aligned in certain directions and whose sites correspond to the tracks of Schiaparelli's time;

'permanency which demonstrates the objective reality of these formations.'

We must therefore, he says, retain the conventional name of 'canals' for these objects, and adds:

'These "canals" are equally interesting whether they are really continuous objects or whether they are made up of aligned detail, because they indicate the particular structure of the surface of Mars.'

M. Fournier then develops the following argument:

'An important characteristic of the canals is their periodicity, and this is a decisive argument in favour of their objective reality.'

From Schiaparelli's, Lowell's and his own observations, M. Fournier considers as 'well established that most of the canals are invisible during the Martian winter, and that it is near the spring equinox that they begin to appear; at first indefinite, broad and pale, not really having the aspect of a true canal. They increase in number as the season advances, narrowing and becoming straighter and darker, as by a kind of condensation of the elements that make them up, to vanish at the end of the autumn,' thus taking part in the general seasonal cycle of the great dark areas of the planet.

But a characteristic of the canals that is known to everybody, he says, is as follows:

'On the exact sites of objects habitually so evasive that their very existence has been questioned, we have sometimes seen considerable formations spring into view and impress their presence on the observer as much by their

length as by their intensity of hue, which is comparable to the darkest seas.'

Among many other cases M. Fournier cites the classic examples of Cerberus, Nepenthes-Thoth,[1] Indus, etc., and concludes:

'Such is the highly circumstantial evidence offered in favour of the real existence of the system of Martian canals.

'This evidence establishes that each canal, faint as its appearance may sometimes be, can be considered as the embryo of a most important topographical formation capable of developing in the more or less immediate future,' and 'that this last confirms the existence of the first, and justifies the original tracings.'

Without unduly prolonging these citations by examining all the other arguments involved, let us only note the revived affirmation of the phenomena of gemination, and that M. Fournier ends by concluding:

'without reserve, that the phenomena of the canals, considered as a whole, are specifically Martian'.

Recourse to Photography

Thus we cannot doubt that there is 'something remarkable on Mars.

But how can we form an objective opinion as to the real aspect, the fine structure of this 'something'?

Perhaps photographs, with their impersonal character will give us some indications?

Alas, these photographs have been called in to support both theories; Antoniadi saw there the confirmation of his drawings, and we have already cited what Slipher

[1] The variations of Nepenthes-Thoth are visible on Pl. IV, 5 to (refer to the nomenclature on Pl. I for identification).

said about them; thus Lowell's photographs examined by two different astronomers enabled the one to affirm that 'not only is the Ganges canal visible, but we can distinguish its duplicity', while the other considered that the photograph was 'the negation of this point of view'!

In reality it seems that these photographs are far too indefinite to enable us to reach any conclusion one way or the other, because the already faint details necessarily appear diffused, whether they be actually so or really very sharp. As Slipher has illustrated elsewhere, comparing a direct photograph of Mars with the photographic reproduction of one of his drawings taken under equivalent conditions, the observer finds himself, with regard to fine detail, nearly under the same conditions of uncertainty as at the time of direct observation.

Unfortunately, therefore, it has not so far been possible to produce planetary photographs rivalling the clearness of direct observation; indeed, that which the eye can grasp in a few tenths of a second in moments of calm can only register very vaguely on the photographic plate, on account of the ever-present turbulence of our atmosphere.

The Present State of the Problem, and Work in Progress

It is not possible here to go deeper into the innumerable arguments and hypotheses advanced with regard to the Martian canal problem.

Each party, 'canalist' and 'anti-canalist', has clung to its position without admitting that the rival theory may nevertheless contain an element of truth—though it would certainly be more reasonable and useful to see whether some measure of agreement could be found.

However, during the last few years new observations

have been made which seem to make some progress in this direction.

During the 1941 opposition, photographs of exceptional quality were obtained by Dr. B. Lyot and his assistants, working with telescopes first of 15-inches, then 24-inches aperture at the Pic du Midi Observatory at an altitude of 9,300 feet, where the telescopic images are frequently of a purity and steadiness unknown at stations at lower levels.

Now, in the unanimous opinion of all those (whether 'canalist' or 'anti-canalist') who have been able to examine them, the photographs unquestionably show—on a background whose aspect is otherwise in good accord with the drawings and maps of Antoniadi—a certain number of single and even double canals, sometimes very narrow, confirmed by simultaneous visual observations.

One of the observers at the Pic, M. Gentili, originally a firm 'anti-canalist', has been led to believe, after the 1941 opposition, that 'certain canals were broad and diffuse, others[1] extraordinarily narrow, but these last were always very short and very black', to call the doubling of certain canals (Nepenthes-Thoth) 'something easy and obvious', and even to describe the two components of a double band crossing a dark region (the Mare Erythræum); and that, says M. Gentili, 'when I had taken every precaution to prevent myself from being carried away and "Lowellizing" my drawings.'

Other fine canals and other geminations (Nilosyrtis) have been recognized since that time by other observers working at the Pic du Midi during the most recent oppositions.

What seems to emerge up to now, from this mixture of

[1] Much rarer than the first type.

visual and photographic observations, is a hybrid representation of the Martian surface neither 'canalist' nor 'anti-canalist', so that we can doubtless hope for the possibility of compromise that appears to have arisen between the two theories.

But the significance of such a hybrid representation seems, at least for the moment, to be very obscure and very difficult to interpret by any of the proposals of the two hypotheses advanced. Finally, we must impartially conclude that the question remains open, and calls for the most energetic research.[1]

[1] During the last opposition (1948), a young and very keen-sighted observer, A. Dollfus, working with a power of 900 on the 60-cm. refractor at the Pic, succeeded, during a night of perfect seeing, in resolving some of the canals—single and double—into minute spots and patches of irregular outline, thus producing the best available evidence, for the time being, concerning the fine structure of the so-called 'canals' of Mars. (Pl. V, 5-6)

LIFE ON MARS?

And now that we have passed the multiple and complex aspects of the planet in review, made the acquaintance of proven results and of those which remain uncertain, we must say a few words about life on Mars, without however attempting to answer the question so often asked: 'Are there any Martians?'

If, during so many years, so many astronomers have passed so many hours watching the planet Mars, have given up so much for it and argued so fiercely among themselves; if more and more physicists have devoted themselves in their turn to the Martian problem, it is, without doubt, because Mars remains the only planet whose phenomena cannot easily be interpreted by the sole use of the physical and chemical laws applied to inorganic matter.

And, indeed, if we could one day come to the certain conclusion that there was actual activity displayed by reasoning minds yonder, what a prodigious upheaval would it cause in human thought! Even if we could only establish that vital phenomena of some sort were going on on the surface of our neighbour planet, very important scientific conclusions and drastic revisions of philosophical opinions would result.

It is doubtless for this reason that the question has not, so far, been properly faced. We have by no means demonstrated that the well-established phenomena cannot be interpreted with the sole aid of the usual laws of

physics and chemistry, but neither have we demonstrated that life could not adapt itself to the known conditions of dryness, temperature, atmospheric pressure and atmospheric composition—after all, not so very different from our own.

Without speaking of the 'Martians', we cannot therefore affirm that there is or is not life on Mars; but we can say, I believe with virtual certainty, that the immense majority of living things on the Earth, if not all of them, would find it impossible to accommodate themselves to the conditions which prevail on Mars. In particular, we ourselves could not live there in the open air.

CONCLUSION

If we now look retrospectively at the results of this mass of research concerning Mars, we can see that, after a necessary period of prospection, areographers have reached the stage of arguing interminably about conclusions reached by visual and qualitative methods of observation—methods which are certainly patient, but manifestly inadequate.

In the course of the last cycle, Astrophysics has happily come to bring the aid of its refined and penetrating methods, sweeping away wrong ideas and bringing results that were often unhoped for, sometimes unexpected; but they have not yet sufficient power to displace the older methods completely.

We can only hope that the next cycle will see the following-up of the question and its final solution; more astrophysicists are devoting themselves to the problems of Mars, and if their researches do not bring us the complete solution of the 'Martian problem', they will at least enable us to make definite progress; and we can thus reasonably hope that at the end of the next cycle, in 1956, the present book will appear very much out of date!

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